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US006136379A

United States Patent [19]

Scarpa et al.

[11] Patent Number: 6,136,379

[45] Date of Patent: Oct. 24, 2000

[54] **METHOD FOR APPLYING METAL-FILLED SOLVENTLESS RESIN COATING**

[75] Inventors: **Jack G. Scarpa**; **James Fletcher Burgess**, both of Huntsville; **John D. Marlin**, Tony; **Matthew Kelly**; **Anthony Howard**, both of Huntsville, all of Ala.

[73] Assignee: **USBI Co.**, Kennedy Space Center, Fla.

[21] Appl. No.: **09/345,151**

[22] Filed: **Jun. 30, 1999**

Related U.S. Application Data

[62] Division of application No. 08/990,209, Dec. 13, 1997, Pat. No. 5,964,418.

[51] **Int. Cl.**[7] **B05D 1/34**

[52] **U.S. Cl.** **427/426**; 427/421

[58] **Field of Search** 427/421, 426, 427/205; 239/418, 421, 424.5

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5,307,992	5/1994	Hall et al.	239/135
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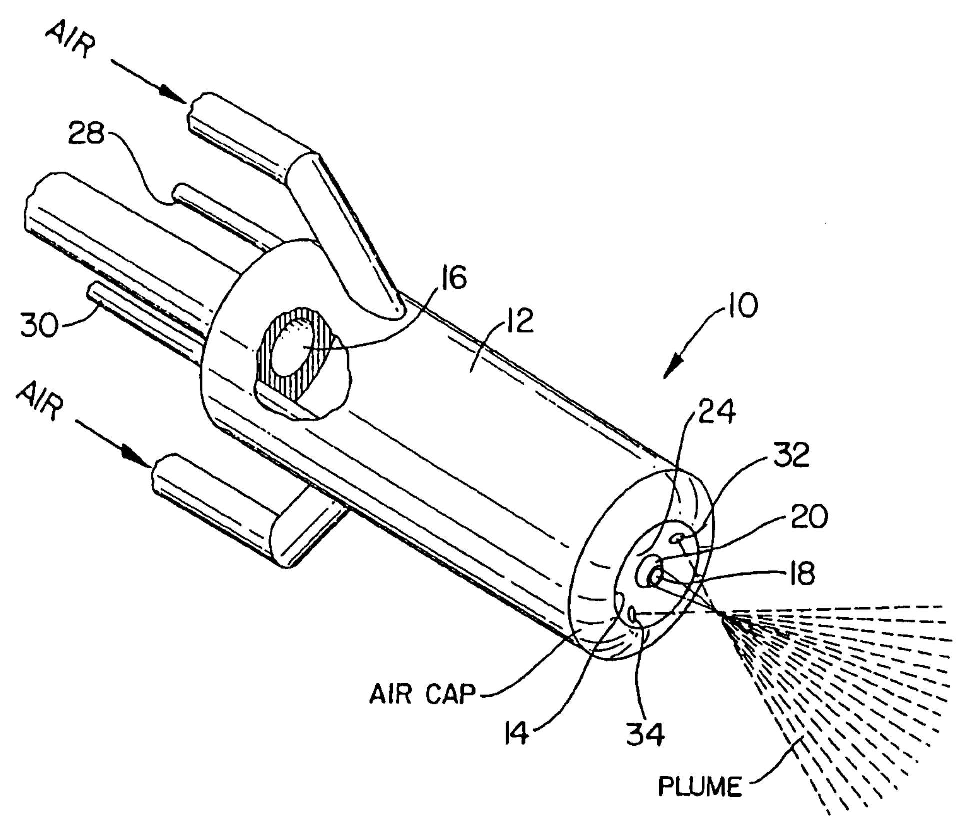
Primary Examiner—Shrive Beck
Assistant Examiner—Jennifer Calcagni
Attorney, Agent, or Firm—Norman Friedland

[57] **ABSTRACT**

A convergent spray gun which combines a liquid resin and dry metallic powder externally of the nozzle of the spray gun that utilizes a pair of diametrically opposing passages disposed at 0° and 90° relative to the central resin discharging orifice where the central orifice is approximately 0.015 inch and the air for atomizing the fluids is approximately 0.187 inch and the atomizing angle is approximately 180°. The metallic filler is added to the plume of the convergent spray at the low pressure section and the ratio of the fluids are controlled by a computerized system. The spray gun, controls and mixing chambers of the resin (two part) and powder fillers are housed in separate rooms and the dust where the powder fillers are metered is controlled.

3 Claims, 4 Drawing Sheets



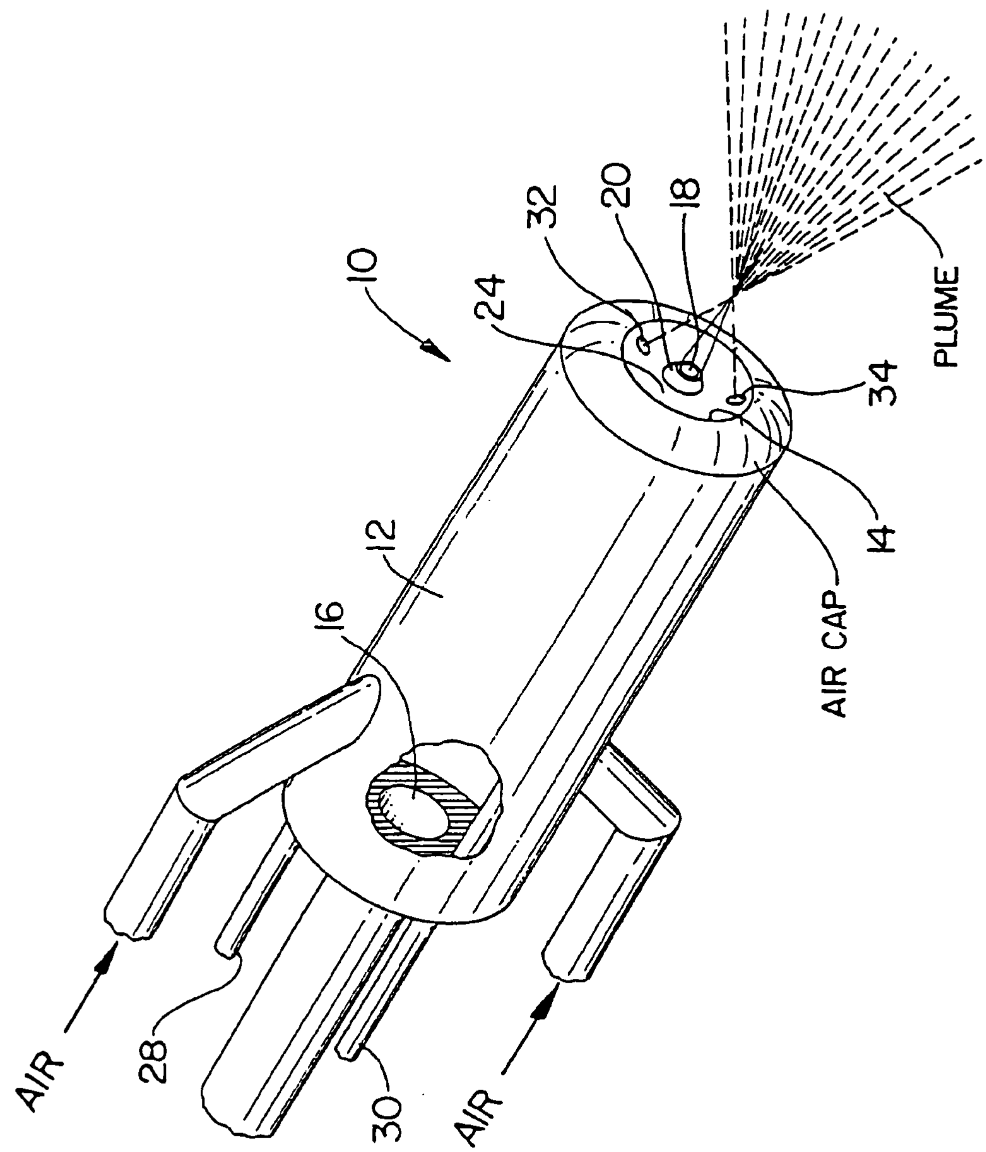


FIG. 1

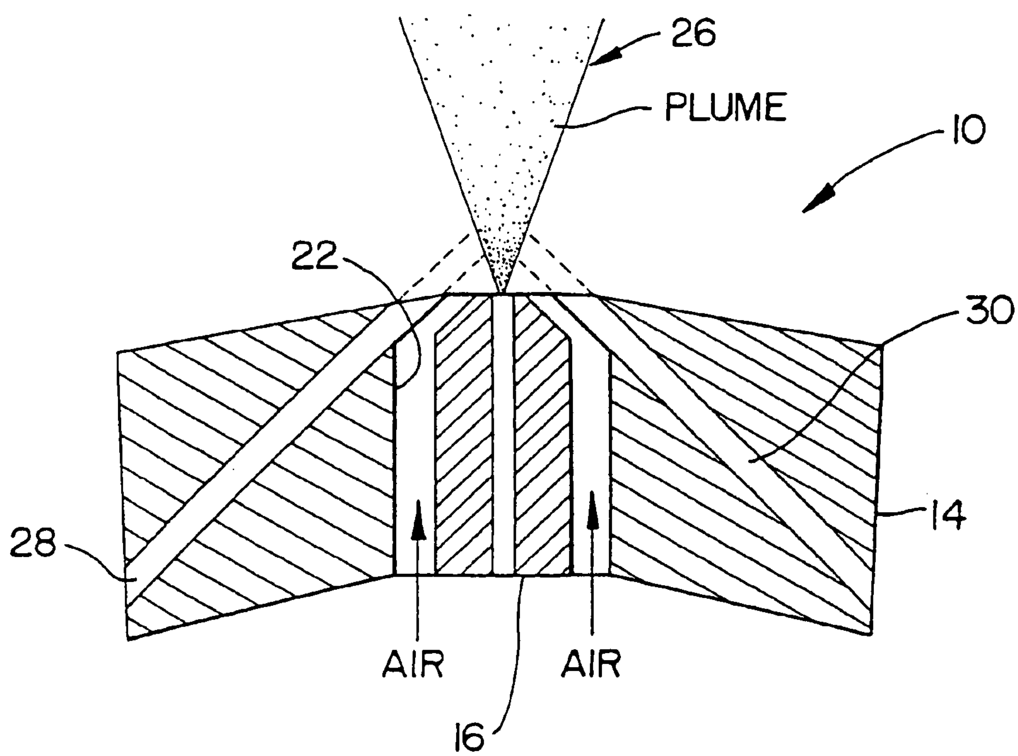


FIG. 2

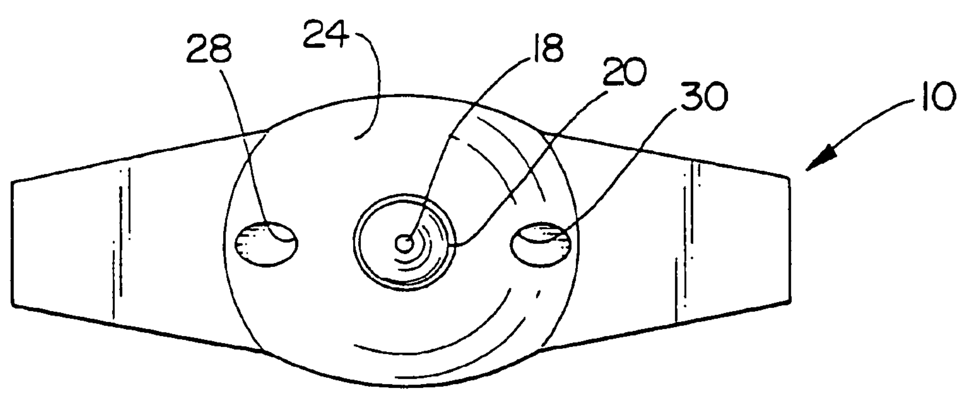


FIG. 3

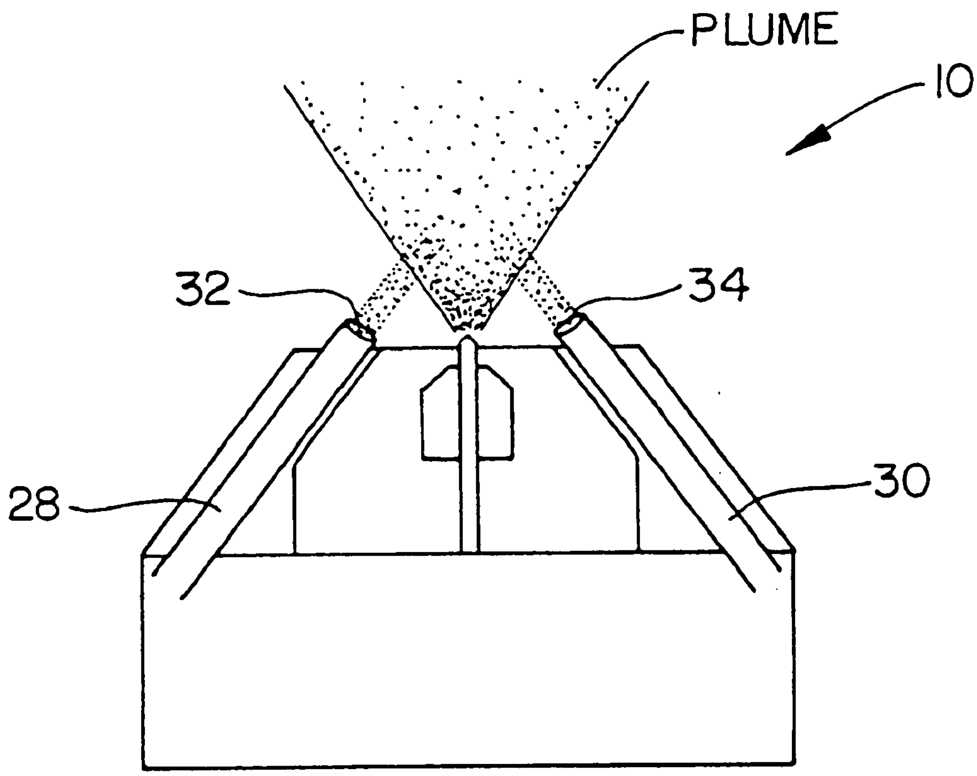


FIG. 4

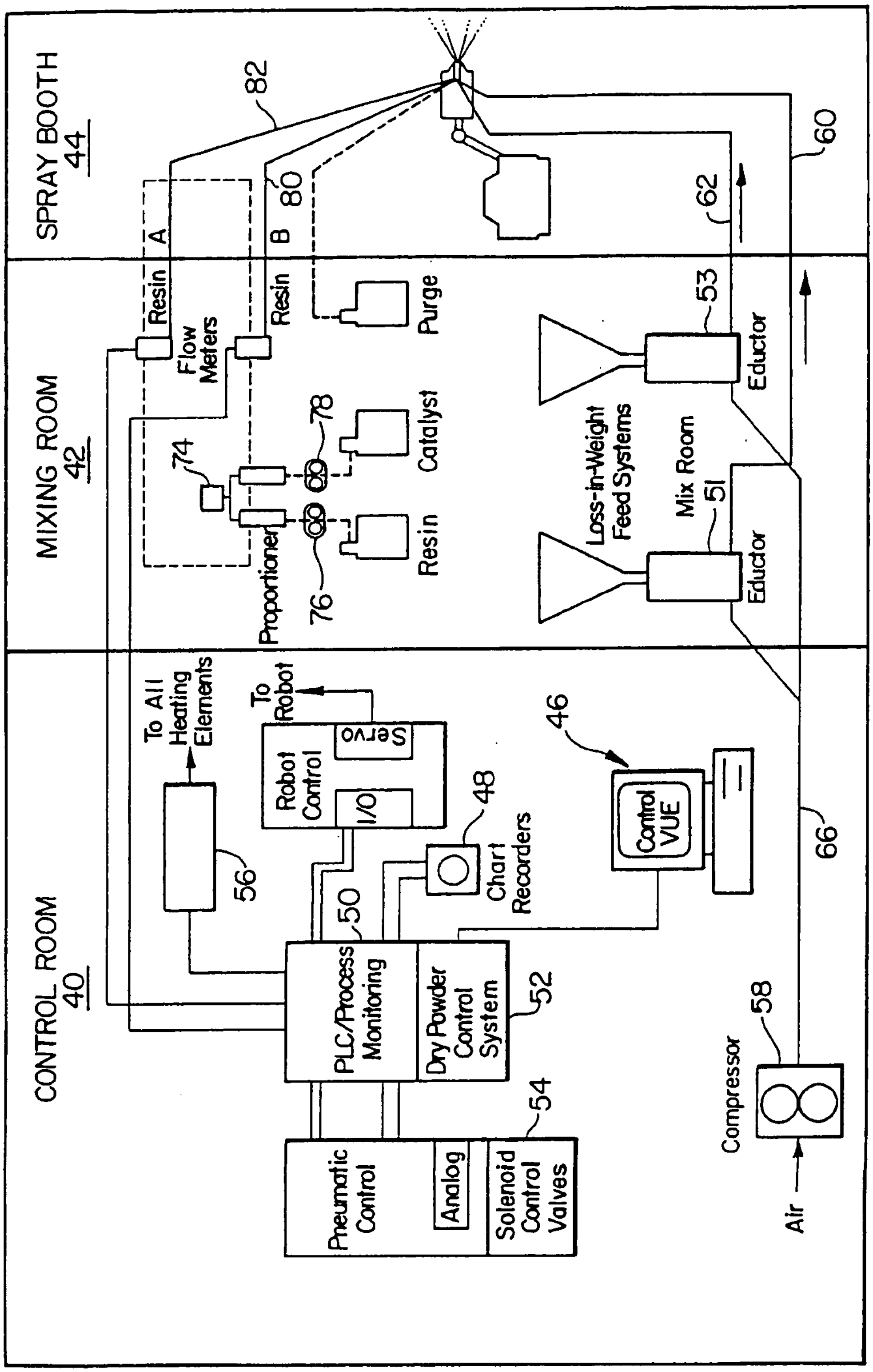

SPRAY BOOTH
44
MIXING ROOM
42
CONTROL ROOM
40
82
A
B
80
60
62
Resin
Flow Meters
Resin
Purge
74
78
Catalyst
Resin
Proportioner
76
53
Eductor
Loss-in-Weight Feed Systems
Mix Room
51
Eductor
To All Heating Elements
To Robot
Robot Control
Servo
I/O
46
Control VUE
48
Chart Recorders
56
50
PLC/Process Monitoring
Dry Powder Control System
52
66
58
Compressor
54
Pneumatic Control
Analog
Solenoid Control Valves
Air

FIG. 5

METHOD FOR APPLYING METAL-FILLED SOLVENTLESS RESIN COATING

This application is a division of application Ser. No. 08/990,209, filed Dec. 13, 1997, now U.S. Pat. No. 5,964, 418.

TECHNICAL FIELD

This invention relates to apparatus and method of applying coatings to a substrate and particularly to the apparatus and method for coating a substrate with highly metallic powdered-filled solventless resins.

BACKGROUND OF THE INVENTION

As is well known in the spray coating technology the heretofore known spray application equipment for coating substrates with conventional high solids have transfer efficiencies that are less than 50% which results in excessive loss of materials, solvents and time. Of significance in this technology is the ecological standards that one must consider since the impact on the quantities of materials, solvents and volatile organic compounds that are released into the atmosphere are not only a major concern of the caring individuals but must comply with the Occupational Safety and Health Administration (OSHA) and the Environment Protection Agency (EPA) requirements. Moreover, the current conventional coating systems presents a myriad of problems including, but not limited to, safety to the operators, environmental hazards, high costs and difficulties encountered when attempting to apply the coating.

There has always been a need for a high solid coating system that would coat the substrate with solids that would be between 5–10 mils thick in one pass without the necessity of a solvent.

We have found that we can provide a uniquely designed spray apparatus and method of applying the spray to the substrate while obtaining substantially 100% solids. The convergent spray technique of this invention will not only obviate the problems alluded to in the above paragraph but will eliminate the use of hazardous materials that would otherwise be used. It is contemplated by this invention to use a forced air stream to introduce the dry metallic filler material into a wet resin stream where it is convergently combined with the resin components. This invention contemplates utilizing a spray nozzle and system that is similar to that disclosed in U.S. Pat. No. 5,565,241 granted on Oct. 15, 1996 to Mathias et al of which Jack G. Scarpa, is a common co-inventor, entitled "Convergent End-Effector" and U.S Pat. No. 5,307,992 granted on May 3, 1994 to Hall et al of which Jack G. Scarpa is a common co-inventor, entitled "Method and System For Coating A Substrate With A Reinforced Resin Matrix" both of which are commonly assigned to USBI Co., and which are incorporated herein by reference. As stated in the U.S. Pat. Nos. 5,565,241 and 5,307,992 patents, supra, the apparatus for applying the coating of reinforced resins matrix to a substrate is a spray nozzle that includes a centrally disposed orifice and a plurality of circumferentially spaced orifice(s) surrounding the center orifice for creating an atomizing zone. Included are other orifices radially spaced outwardly from these orifices which are used for shaping the spray. Reinforcing material is introduced to the resin through the aft end of an encircling chamber or manifold that surrounds the spray nozzle and is designed to feed the reinforcing material to the liquid resin. Pneumatic eductor lines for conducting compressed air are utilized to transport the materials to the substrate.

The present invention modifies the circumferential air atomization cap of heretofore known spray nozzle to include a central orifice that measures approximately 0.187 in diameter and includes an atomization angle of 90°. The filler is concentrated into two distinct streams thus eliminating the buildup of the material on the surfaces and crevices of the spray applicator and transfer lines. This will result in enhanced transfer efficiencies and a more consistent finish of the coating on the substrate surface. The method employed utilizes a hopper and gravity fed loss-in-weight feed system under control into an eductor manifold system that transports the filler material through two separate streams prior to arrival at the spray applicator. A constant dry filler to liquid resin ratio assures a consistently applied coating.

By controlling the amounts and rates of resin and dry metallic filler and the proper ratios for coating selected surfaces, the entire system delivers, meters and mixes these materials only on demand of the convergent applicator with a consequential elimination of the requirement to pre-mix the coating formulations. This convergent spraying technique for dry fillers and resins provide a uniform controllable coating and if desired, this invention contemplates the option of heating the separate resins (when two or more resins are utilized) so as to accelerate the gel times of the sprayed materials. This optional method enhances the coating since it allows for a uniform buildup of the coating.

This invention has been particularly efficacious for solvent less application of Mag Ram type of coatings (stealth applications) and highly filled zinc or other metallic fillers for corrosion resistance.

The system and spay nozzle of this invention also provides the following improvements, although not limited thereto, over the heretofore known system:

- This system is compatible with epoxy, polyurethane, silicate water base or 100% solid resin systems;
- This system has the ability to more accurately control thickness of applied coating;
- This system has the ability to control the dimensions of surface area to be coated;
- This system has the ability to control both filler and resin material independently;
- The system reduces the number of required passed to attain a desired thickness of the coating in contrast to solvent borne systems;
- This system reduces waste and hazardous materials;
- This system has the propensity of reducing of time required to apply coating, reducing the time to test MagRam properties of coatings, and reduces solvents (VOC's) to apply zinc rich coatings; and
- This system optimizes the loading capabilities by allowing the loading to be between 0%—a high of over 90%. This is also dependent upon resin and atomization characteristics of resin compenents.

DISCLOSURE OF THE INVENTION

An object of this invention is to provide improved spray nozzle apparatus for applying metal filled coatings to a surface of a substrate.

Another object of this invention is to provide spray nozzle apparatus that is capable of achieving a solution that is 100% solids and applying a substantially thick coating without the use of solvents and the thickness could range as much as 5–10 mils in one pass.

A feature of this invention is a convergent spray applicator utilized forced air stream to introduce the dry metallic filler

into the wet resin stream where it is convergently combined with the resin components. Two distinct streams are utilized for the concentrated dry filler that eliminate the buildup of material on the surfaces and crevices of the spray applicator and the attendant transfer lines. This system is characterized as affording the advantages enumerated in the above paragraphs.

The method of applying the coating is transporting the filler material through two separate lines by a manifold controlled loss-in-weight a volume feed system that is gravity fed from a hopper containing the filler material. The system maintains a constant dry filler to liquid resin ratio to assure a consistently applied coating.

A feature of this invention is the arrangement of the various components of the convergent process system by designating certain components of the process and assigning them in separate rooms or areas and controlling the mixing of the components of the coating in a dust free separate room and utilizing robotics to position the spray gun and a control system remotely located from the spray booth housing the spray gun and substrate.

Another feature of this invention is the method of coating utilizing a metallic powder filler combined with a liquid resin at the exterior of a convergent spray coating nozzle of the spray gun prior to the application of the coating on a substrate.

The foregoing and other features of the present invention will become more apparent from the following description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view in perspective illustrating the convergent spray nozzle of this invention;

FIG. 2 is a partial elevation view in section illustrating the air cap portion of the convergent spray coating nozzle of this invention;

FIG. 3 is a top down plan view of the front end of the spray nozzle illustrated in FIG. 2;

FIG. 4 is a schematic of the atomization air cap of the spray nozzle of FIG. 2 illustrating the relationship of the resin and powder feed lines and coating mixture just prior to application on the substrate surface; and

FIG. 5 is a schematic partly in block diagrammatic illustration of the system utilized in proportioning the materials utilized in the coating, transporting the materials and the controls therefore.

These figures merely serve to further clarify and illustrate the present invention and are not intended to limit the scope thereof.

BEST MODE FOR CARRYING OUT THE INVENTION

While this invention shows in the preferred embodiment the spray nozzle apparatus and system for coating the substrate with Mag Ram or Zinc it is to be understood that other metallic material for coating the substrate can be utilized without departing from the scope of this invention. Also, it is noted that although these materials are described as being utilized for radar adsorption and corrosion applications this invention contemplates that other materials may be used for these purposes and for other purposes. As one skilled in this technology will appreciate, this invention is directed to introduce dry metallic filler into the wet resin downstream of the nozzle's orifices where it is convergently combined with the resin components just prior to being sprayed on the surface of the substrate. In the preferred embodiment the system is automated and computer controlled utilizing the requisite pumps, valves, actuators, sensors and robotics to position the spray nozzle relative to the substrate. It being understood that this invention can be practiced without the utilization of automation.

The invention can best be understood by referring to all the FIGS. where FIG. 1 shows the convergent spray nozzle generally illustrated by reference numeral **10** as having a cylindrical housing **12** including the air cap **14** supporting the tubular resin conveying member **16**. The spray nozzle **10** may be a suitable commercially available nozzle that is modified in accordance with this invention. a suitable commercially available nozzle can be the spray nozzles manufactured by Binks, located in Franklin Park, Ill. The resin conveying member **16** includes a centrally disposed discharge orifice **18** for injecting the liquid resin into the airstream created by the annular orifice **20** surrounding the central orifice **16**. The orifices are designed to provide an atomized convergent spray in much the same manner as that disclosed in the U.S. Pat. No. 5,565,241 patent, supra. For further details of the spray nozzle reference should be made to this patent. Suffice it to say that instead of the surrounding circumferentially spaced individual orifices for injecting the air for atomization purposes this nozzle is configured to include the annular orifice **20** (FIG. **3**) judiciously sized to substantially equal 0.187 inch. The orifice **18** is preferably sized to equal substantially 0.015 inch. As one skilled in the art will appreciate, the sizes of the orifices and their orientation relative to each other are important aspects of this invention since it is necessary to achieve satisfactory mixing of the ingredients prior to the application on the substrate. The air passage **22** (FIG. **3**) in the air cap is contoured so that the surface **24** defines an angle so that the air being discharged from orifice **20** may be between 20 degrees(°)–90° at the point where it converges with the plum and preferably is substantially equal to 90° taken through any vertical plane and is centrally oriented with the discharge from the orifice **18**. This provides the proper convergence and assures that the plume of the liquid resin when atomized takes the shape indicated by the plume **26**.

As will be more fully explained herein below, it is abundantly important that the powder injected into the resin becomes completely wetted and homogeneous with the resin to assure a uniform and consistent finish of the coating on the substrate surface. As is disclosed in the U.S. Pat. No. 5,565,241 patent, supra, the liquid resin is fed to the discharge orifice **18** where it is combined with the air to form an atomized spray. In the event more than one resin is desired a second resin or other constituents may be mixed immediately prior to being admitted into the spray nozzle. Obviously, the exact sizing of the orifices **18** and **20** will be predicated on the particular resins selected and the desired droplet size and pressure necessary to perform the desired mixing to achieve the homogeneous mixture. In the preferred embodiment the viscosity of the liquid resin should be in the 1,000 to 5,000 centipoise (cps) range. In fact, the particular parameters for achieving the desired coating is within the purview of one skilled in this art, recognizing the diameter sizes indicated in the above paragraph of orifices **18** and **20** are the preferred. The viscosity may also be controlled by applying heat thereto in a well known manner.

In accordance with this invention the fine metallic powder is introduced to the liquid resin by two judiciously oriented streams **28** and **30** (FIG. **4**) feeding judiciously oriented discharge orifices **32** and **34**, respectively. The filler material that is transported by the air stream as will be explained in

more detail hereinbelow is judiciously angled relative to the plume of the resin and introduced to the plume at a given location as shown in the Figs. in order to achieve the desired uniformity and consistency of the coating. The diametrically disposed discharge orifices **32** and **34** are at 0° and 180°, respectively, The parameters for the discharge orifices **32** and **34** will be predicated on a number of parameters, such as transport air pressure, particle sizes, density, type of material, etc. that are within the skilled artisan. What is of the utmost importance is that the passages **28** and **30** and the respective orifices **32** and **34** are oriented to introduce the filler at the low pressure point of the plume so that these two streams will eliminate the buildup of the material on surfaces and crevices of the spray applicator and the attendant transfer lines while assuring the consistent finish of the coating on the substrate surface.

As alluded to in the above paragraphs, this invention contemplates maintaining a constant dry filler to liquid resin ratio to assure a consistently applied coating. As will be detailed herein below the system delivers, meters and mixes the required materials in proper ratios to attain the proper amounts and rates of material only on demand of the convergent applicator. This will result in a system that eliminates the requirement to pre-mix the coating formulation. This system is describe in connection with FIG. **4** which indicates that the process is best achieved by separating certain functions of the system in three distinct rooms or areas which consist of the control room **40**, the mixing room **42** and the spray booth **44** (FIG. **5**).

The entire process is controlled by a suitable general purpose computer generally illustrated by reference numeral **46** which is suitably programmed by any skilled programmer to generate the desired signals to attain the proper flows and ratios and should include, but not necessarily required, a recorder **48** to obtain a read out of the activities of the process, and a PLC process control **50**. The processor includes suitable control mechanism for controlling the various components as represented by box **54**, such as the gun trigger, solvent flush, air transports, dry powder and resins via the various solenoid control valves in the system. The process control also monitors the amounts for the various materials and in a well known manner processes a hard read out copy. In applications where heat is applied the control room **40** would house the suitable relays **56** for actuating the desired heating elements (not shown) but would be of the type described in the U.S. Pat. No. 5,565,241 patent, supra.

As noted in FIG. **5** the computer **46** in the control room **40** serves to control the rates of flow of the dry powder by actuating the eductors **51** and **53** in the mixing room **42** and the air compressor **58** in the control room **40**. The eductors are a loss-in-weight feed system of the type that is described in the U.S. Pat. No. 5,565,241 patent, supra. Obviously, the dry powder system includes a hopper for the fine particle fillers and serve to maintains a constant volume or weight of powder by replacing the amounts that are being utilized by the spray applicator which are transported thereto by the relatively low air pressure lines **60** and **62**. Each eductor **51** and **53** are connected to the air lines **60** and **62** and receive the compressed air from pump **58** via line **66** and branch line **68**. The resin which may include a catalyst is metered to the spray nozzle by the flow metering valves **70** and **72** which are controlled by the computer **46** in order to maintain the proper amounts and proper ratio relative to the powder filler. The resin and catalyst which are contained in vats are proportioned by a suitable proportioner **74** and pumped to the spray nozzle via pumps **76** and **78** and delivered to the spray nozzle via flow lines **80** and **82**. A purging system may be included in order to clean the nozzle at appropriate times. The dust content of the mixing room that contains the eductors, loss-in-weight feed system and supply of the resin components and filler material is controlled to assure that the coating is free of foreign matter so as not to contaminate the finished coating.

The spray gun which is isolated in the spray booth, may be robotically operated by asuitable robot such as the GMF robot which is controlled by the robot controller in a well known manner.

The following is an example of a the inventive method utilizing the inventive spray nozzle for applying a high solid coating with more than 90% metal filled applied to the substrate surface to obtain a coating thickness of substantially between 5–10 mil in one pass. It will be noted that the filler is transported to the gun and mixed with the liquid resin at the discharge end of the spray nozzle without the use of any solvents. While this example is presented to illustrate the process of coating a substrate with particular materials, it is to be understood that this example is not to be interpreted as being a limitation of the scope of this invention.

EXAMPLE

1. Iron type powder is transferred pneumatically through two (2)½ inch inside diameter Teflon coated hoses and combined with a two (2) part polyurethane epoxy system using the convergent spray technology of this invention to create a uniform, ten (10) mil thick coating.
2. The iron powder is delivered to the two (2) eductors using vibratory feeders which accurately control the feed rate of 4500 grams per hour by means of the PLC monitoring system **52**. eductor air pressure is at 10–12 pounds per square inch (psi) which is sufficient air pressure to move iron particles to the spray gun. All air pressure is controlled through a Pneumatic Control System using solenoid control valves **54** to regulate individual pressures to specific devices.
3. Gear pumps are used to accurately transfer the two (2) part polyurethane epoxy to the spray gun at a rate of **8** cubic centimeters (cc) per minute for each liquid. Both epoxy components are heated to 110° Fahrenheit (F) inside pressure pots. The lines carrying the fluid have an internal diameter of ¼ inch and carry the fluids through flow meters **70** and **72** for an accurate flow measurement. Both fluid lines are heated to 110° F. using electric heat tape **56**.
4. The fluids, after being combined while passing through a mixing chamber, exit through a 0.0015 inch orifice a the tip of the fluid nozzle. Atomizing air, flowing at approximately 30 psi, propels the fluid into a mist. All feed rates pressures and temperatures are controlled by the host P.C. using Control View software.
5. A GMF robot is used to move the spray gun across the substrate in an even manner at a stand off of eight (8) to ten (10) inches. Each pass of the spray gun overlaps one (1) inch. The spray gun moves at a rate of six (6) to eight (8) inches per second.

While the example detailed in the immediately above paragraph illustrates a coating utilizing an iron filler, it will be obvious that other metallic fillers such as zinc may be equally utilized by this invention. The coating was highly loaded with solids (70–85% metal filled) and the thickness of the coating was between 5–10 mils that was achieved in one pass. The metal filling required no solvents as the convergent spray nozzle made the mixture of the metal filling and liquid resin on the exterior of the spray nozzle.

Although this invention has been shown and described with respect to detailed embodiments thereof, it will be

appreciated and understood by those skilled in the art that various changes in form and detail thereof may be made without departing from the spirit and scope of the claimed invention.

It is claimed:

1. The method of producing a five to ten millimeter thick coating on a substrate wherein the coating contains a metallic filling of a given proportion to the resin utilized to support the metallic filling on the substrate comprising the steps of:

0. providing a spray gun;
1. providing and transmitting metallic powder through a pair of hoses coated with a polymer of tetrafluoroehtylene and having a given inside diameter, a pair of eductors and a pair of vibratory feeders and controlling the feed rate at 4500 grams per hour by the use of a PLC monitoring system, and a pneumatic control system for conducting the metallic powder to the spray gun,
2. providing and pumping a two part polyurethane epoxy to the spray gun at a rate of 8 cc per minute for each liquid and applying heat to the epoxy to increase the viscosity,
3. Regulating the flow of the liquid polyurethane epoxy and metallic powder to attain a given ratio of the amounts of metallic powder and resin,
4. Conducting the resin after passing through a mixing chamber that includes a catalyst through a 0.015 inch orifice in the tip of the nozzle in the spray gun,
5. providing atomizing air flowing at substantially 30 pounds per square inch to propel the liquid resin into a diverging mist formed in a convergent plume, and
6. flowing the metallic powder to diametrically opposed nozzles that are mounted on the spray gun and are external of and on either side of the 0.015 orifice so that the metallic powder does not come into contact with the resin until the resin is discharged from the orifice and combining the metallic powder to the resin in the diverging mist and applying the mist to the substrate.

2. The method of claim **1** including step of supporting the spray gun by a controlled robot for moving the spray gun at a rate of 6 to 8 inches per second and locating the spray gun at a stand-off of 8 to 10 inches and allowing a pass of the spray gun to overlap approximately 1 inch.

3. The method of claim **2** including the step of controlling the dust content in the room housing the eductors and vibratory feeders.

* * * * *

US005621443A

United States Patent [19]

Buschulte et al.

[11] **Patent Number: 5,621,443**

[45] **Date of Patent: Apr. 15, 1997**

[54] **INK-JET DEVICE AND METHOD OF OPERATION THEREOF**

[75] Inventors: **Rainer Buschulte**, Bad Schönborn; **Helmut Kipphan**, Schwetzingen, both of Germany

[73] Assignee: **Heidelberger Druckmaschinen AG**, Heidelberg, Germany

[21] Appl. No.: **311,202**

[22] Filed: **Sep. 23, 1994**

[30] **Foreign Application Priority Data**

Sep. 23, 1993 [DE] Germany 43 32 264.6

[51] **Int. Cl.**[6] **B41J 2/02**

[52] **U.S. Cl.** **347/73**; 347/20; 347/75; 347/82

[58] **Field of Search** 347/20, 73, 74, 347/75, 76, 77, 82, 83

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Primary Examiner—John E. Barlow, Jr.

Attorney, Agent, or Firm—Herbert L. Lerner; Laurence A. Greenberg

[57] **ABSTRACT**

Ink-jet device for producing an image on a recording medium includes a droplet-producing device for ejecting droplets along a trajectory, and a droplet-controlling device for controlling the trajectory of the droplets, the droplet-controlling device being formed as a deflection surface, the deflection surface being disposed so that respective droplets impact thereon and rebound to continue the flight thereof, the respective droplets being splittable into at least two subdroplets as a function of selected parameters, and ink-jet process.

trajectory

28 Claims, 5 Drawing Sheets

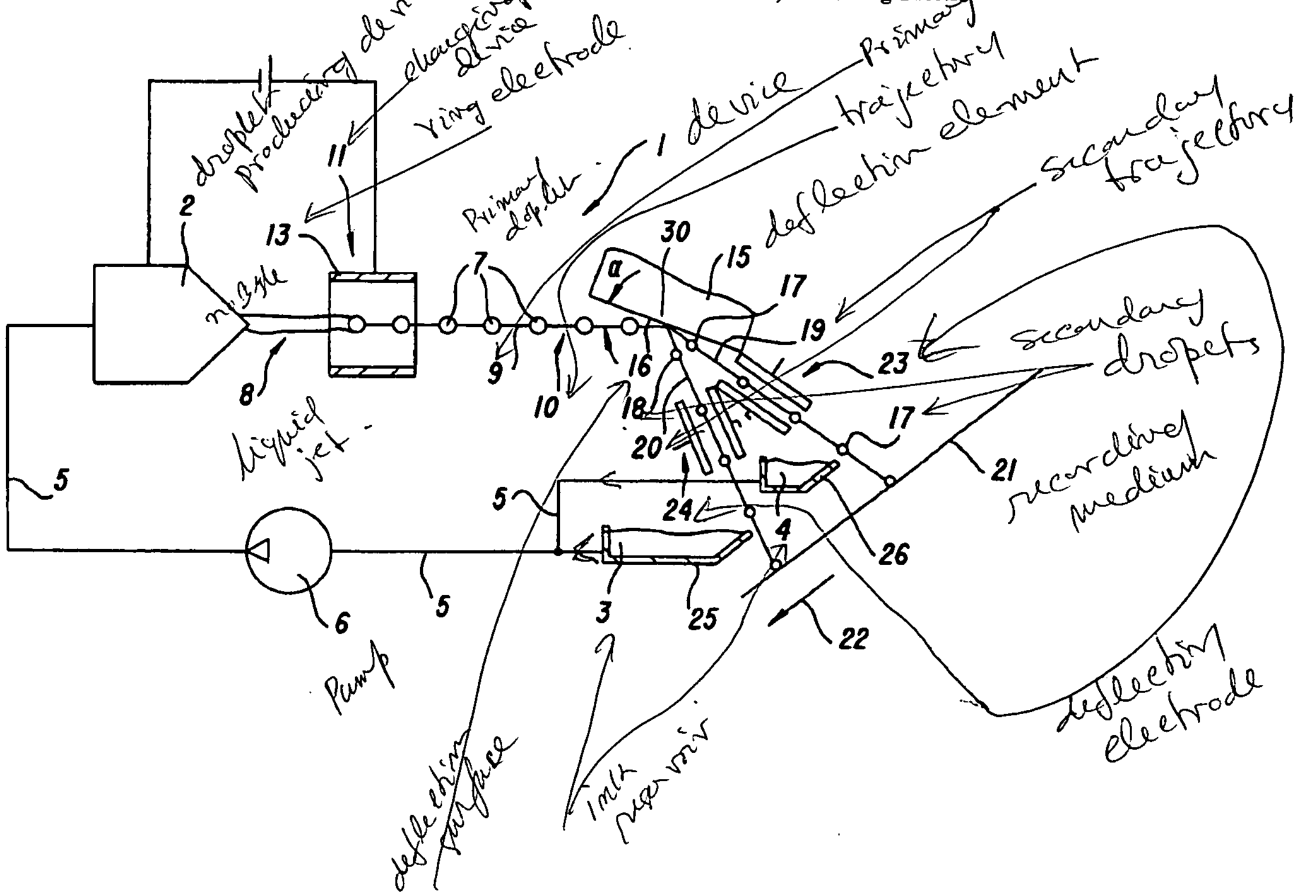

Fig.1

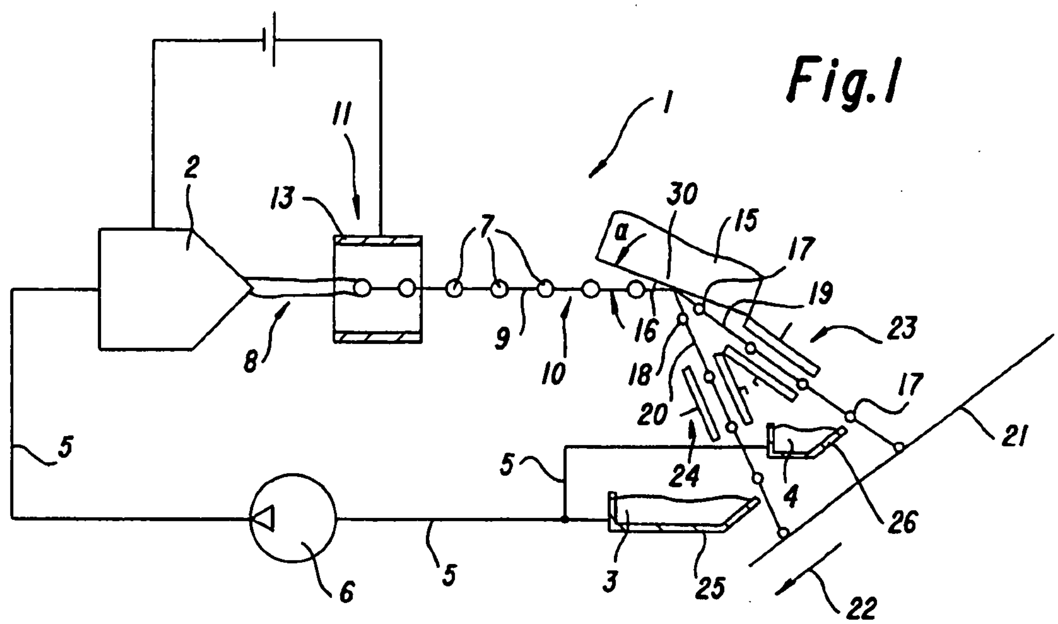
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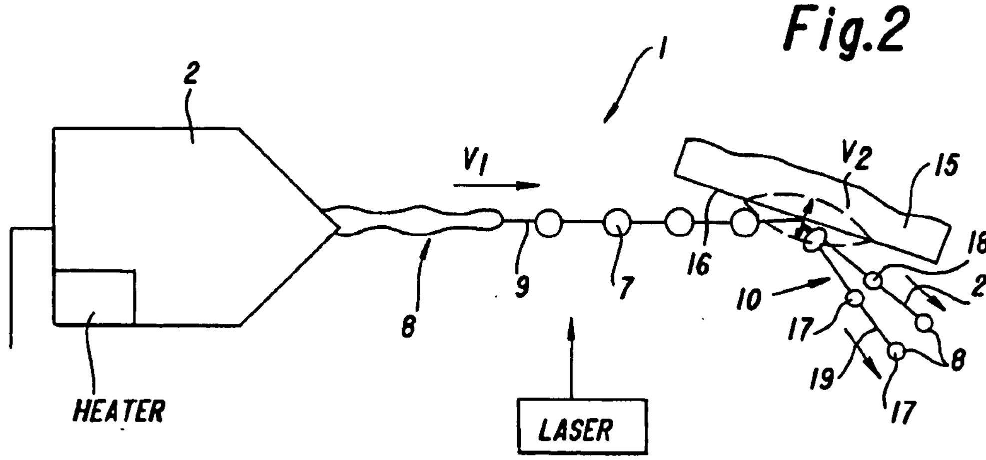
Fig.2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HEATER
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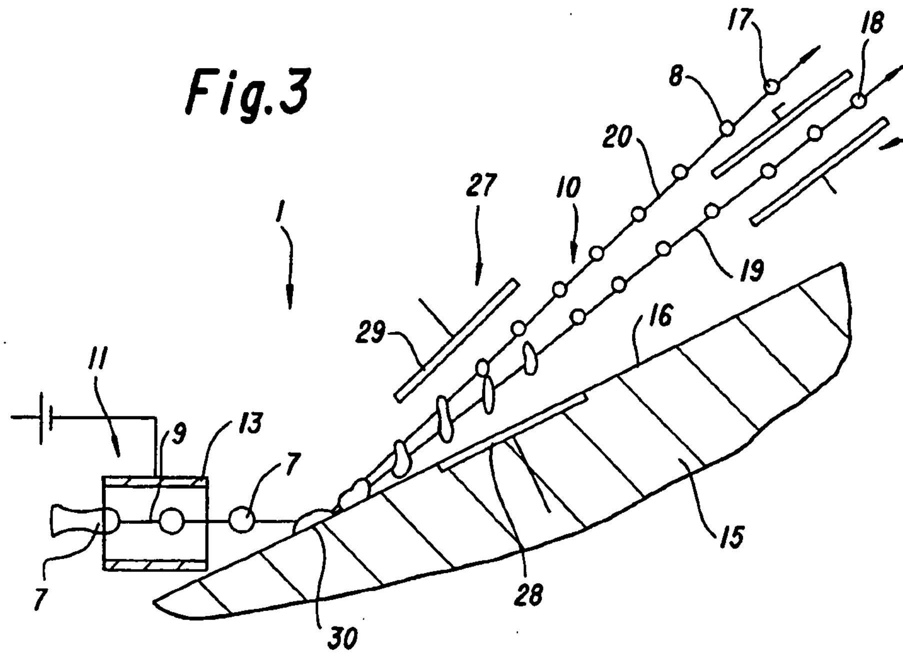
Fig.3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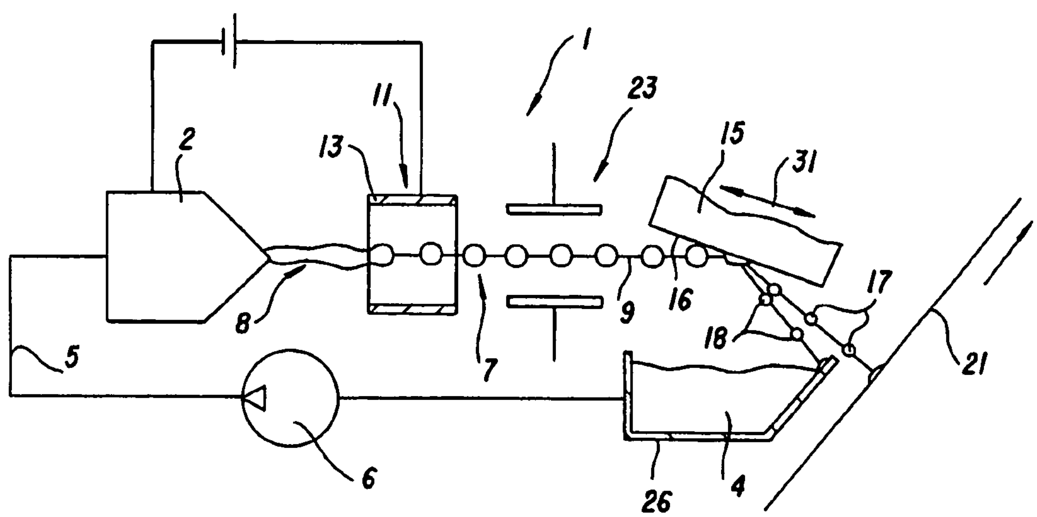
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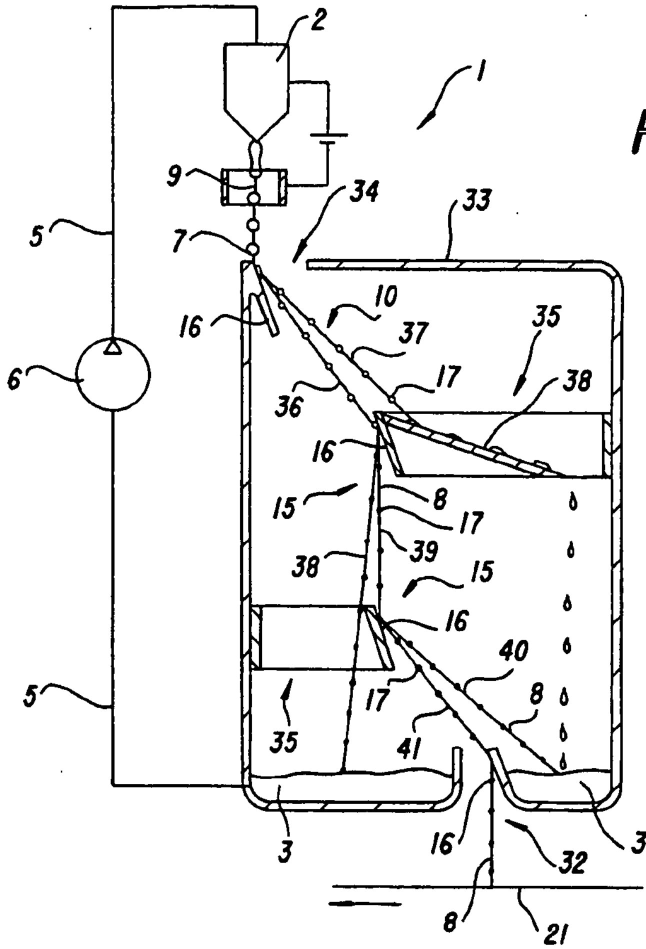
Fig.4


2
1
9
34
33
5
7
10
16
37
35
6
36
17
38
16
15
8
17
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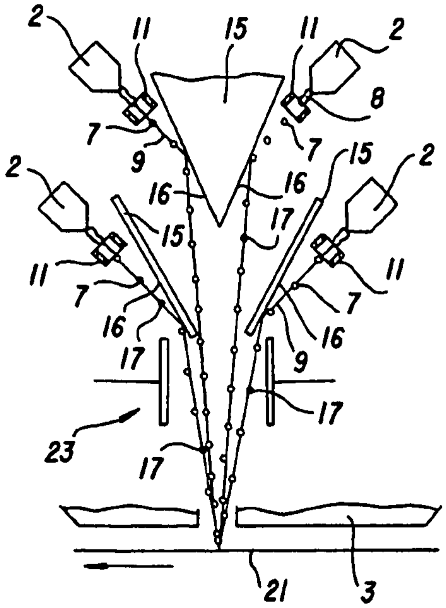
32
3
8
21

Fig.5


2
11
15
11
2
8
7
9
7
15
2
2
16
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15
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11
7
7
11
16
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17
9
23
17
17
21
3

Fig.6

Fig.7

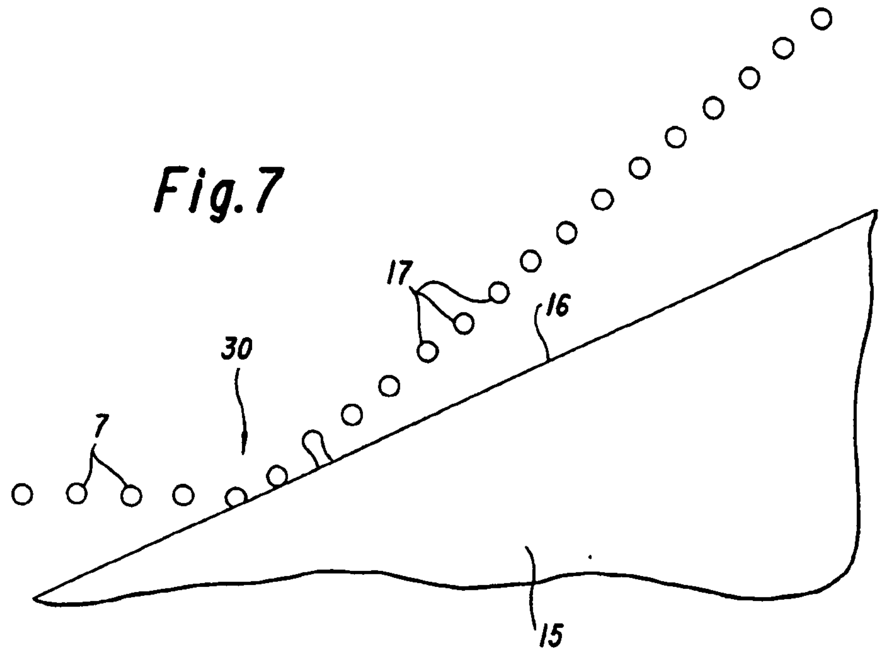


Fig.8

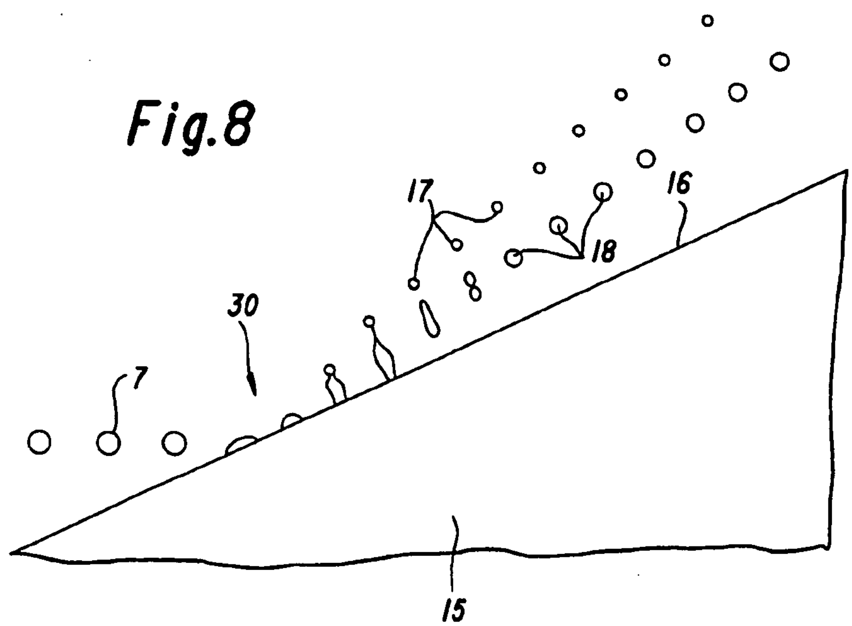
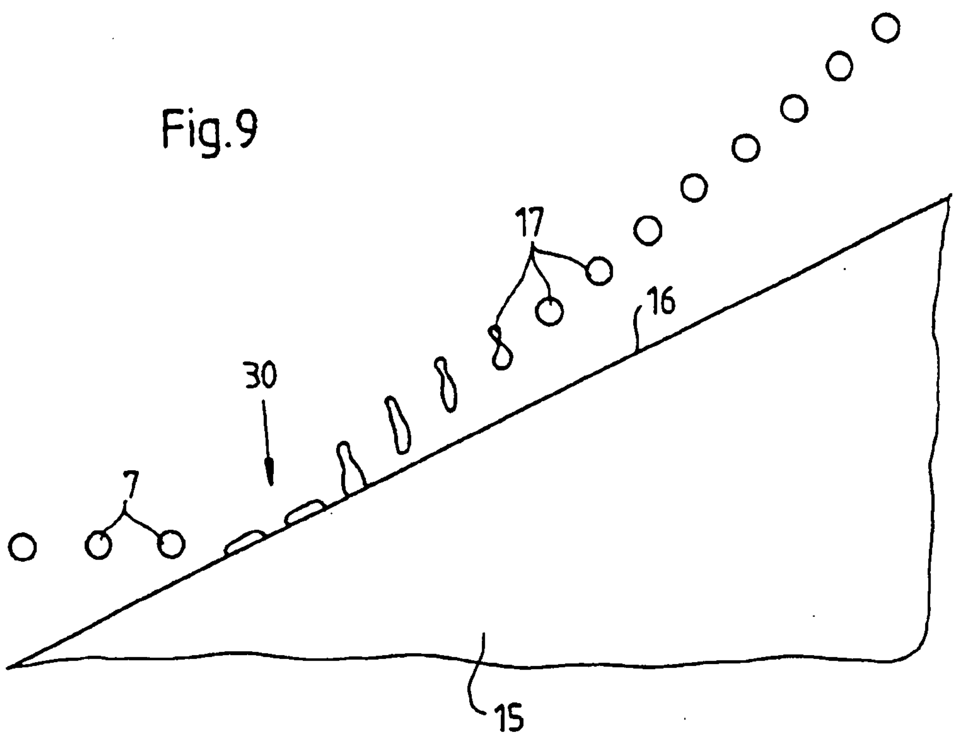


Fig.9



INK-JET DEVICE AND METHOD OF OPERATION THEREOF

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to an ink-jet device, more particularly, for producing an image on a recording medium, including a droplet-producing device for ejecting droplets along a trajectory, and a droplet-controlling device for controlling the trajectory of the droplets.

2. Description of the Related Art

An ink-jet device of the foregoing general type has become known heretofore from published European patent document 0 223 375 B1. The device described therein includes a droplet-production device for ejecting droplets along a trajectory. On their way to a recording medium, the droplets pass a droplet-controlling device in the form of an electrode arrangement. Situated between the electrode arrangement and the droplet-producing device is a charging device, which applies an electric charge to the droplets as they move along their trajectory. When the electrically charged droplets pass the aforementioned electrode arrangement, it is possible to alter their trajectory due to the application of a corresponding voltage to the electrode arrangement. A result thereof is that the droplets either are caused to impact on the recording medium or, alternatively, are conducted to a droplet-collecting devices and, after having been collected thereat, are returned to a reservoir. The thus recovered ink is then available once again to be resupplied to the droplet-production device. The size of the droplets, i.e., the ink volume thereof, and thus the magnitude of the inking occurring on the recording medium, is dependent upon the construction of the droplet-producing device, which conveys a "chain of droplets", the individual droplets of which, respectively, have a constant volume. It is disadvantageous that, therefore, only a small number of ink shades or color gradations is available and that only a relatively coarse resolution can be achieved.

SUMMARY OF THE INVENTION

It is accordingly an object of the invention, to provide an ink-jet device of the foregoing general type which allows the formation of a great number of gray levels and color shades or gradations, respectively, and permits a fine resolution.

With the foregoing and other objects in view, there is provided, in accordance with the invention, an ink-jet device for producing an image on a recording medium, comprising a droplet-producing device for ejecting droplets along a trajectory, and a droplet-controlling device for controlling the trajectory of the droplets, the droplet-controlling device being formed as a deflection surface, the deflection surface being disposed so that respective droplets impact thereon and rebound to continue the flight thereof, the respective droplets being splittable into at least two subdroplets as a function of selected parameters.

By means of the deflection surface according to the invention, it is thus possible to split preselectively defined droplets of the chain of droplets ejected by the droplet-producing device, with the result that the primary droplets develop into secondary droplets of smaller volume as compared with the primary droplets. Depending upon the respective operating state, chosen on the basis of the selective parameters, it is thus possible to decide whether defined

droplets split or do not split when they impact the deflection surface. Furthermore, the parameter control makes it possible to determine into how many subdroplets a primary droplet is to split. Finally, it is also possible, by means of the parameter control, to adjust or set the relative sizes of the individual volumes of the resulting secondary droplets. As mentioned hereinbefore, splitting of the droplets results in streams of secondary droplets, the droplets of which have a selective volume. Hence, it is possible, for example, to produce very fine droplets or, alternatively, droplets with a larger volume. It becomes apparent therefrom that the recording medium is inked in a corresponding manner; that is, if the droplets are small, there is only very little inking, whereas, if the droplets are large, there is strong inking. It is thus possible to produce a desired number of gray levels or gradations of color and, particularly if very small droplets are produced, a high resolution of the image contents is assured. A side effect of the impacting of the primary droplets on the deflection surface is that their trajectory is affected; that is, the direction of the trajectory of a droplet changes as a result of impact on the deflection surface. There results either just one new trajectory, namely the secondary trajectory, along which droplets, namely secondary droplets, move insofar as there has been no splitting. If, however, the impact on the deflection surface leads to the splitting of the droplet, then there result at least two secondary trajectories, which extend in different directions; that is, they diverge. It is possible to use both chains of droplets to produce the image on the recording medium or to "block out" at least one of the chains of secondary droplets. Blocking-out is effected by collecting; that is, the corresponding secondary droplets are supplied preferably to a collecting vessel and are recycled to the droplet-producing device. Throughout the instant application, the word "ink" (also in conjunction with the term "ink-jet device") signifies that use is made of an inking medium, of whatever kind, in order to produce a marking on the recording medium. There is, therefore, no restriction to the word "ink".

In accordance with another feature of the invention, the droplets impact at a given region of the deflection surface, and a heating device is provided for heating the droplet-impact region of the deflection surface. The heating apparatus makes it possible for the deflection surface, or at least that region of the deflection surface on which the primary droplets impact, to be brought to a desired temperature. It is preferable to adjust thereat the so-called fluid-specific Leidenfrost temperature (approx. 100° C. above the evaporation temperature of the liquid/ink used), with the result that the primary droplets strike a "hot wall" from which they reversingly rebound, forming a vapor cushion. The adhesion of liquid to the deflection surface is completely prevented in this manner. The impacting droplets undergo elastic reflection as they strike the deflection surface, which is inclined in relation to the direction of flight of the primary droplets. It is possible, as a function of the aforementioned parameters, that is, in the instant example, the temperature and the angle of inclination of the deflection surface, to adjust or set whether, after striking the deflection surface, the primary droplets "burst" into subdroplets or whether the droplet is merely diverted while the volume thereof remains unchanged. To be cited in this connection as further parameters, which can be used individually or in any combination, are also the velocity of the droplet in relation to the deflection surface; the influencing of the droplets by means of an electric field; the surface characteristics and material of the deflection surface; and also the temperature of the droplet liquid itself. The various possibilities of control, through the

choice and specification of the magnitude of the parameters, will be discussed in greater detail hereinbelow.

In accordance with a further feature of the invention, the ink-jet device includes a droplet-heating device. The droplet-heating device imparts a desired temperature to the primary droplets; that is, the droplet liquid is heated to a desired temperature, this making it possible to influence the conditions on impact with the deflection surface. It is thus possible to select whether droplet splitting results in two subdroplets with approximately equal volumes or with different volumes. The sizes of the individual volumes can be specified in a desired manner by the aforementioned measure.

In accordance with an added feature of the invention, the droplet-heating device is cooperatively associated with the droplet-producing device so that the droplets ejected by the droplet-producing device are at a selective temperature.

In accordance with an additional feature of the invention, the droplet-heating device is disposed so as to be able to act upon the droplets while they are in flight.

In accordance with yet another feature of the invention, the droplet-heating device is formed as a laser for heating the droplets in flight.

Thus, additionally or alternatively, it is also possible for the droplet-heating device to act on droplets in flight, in particular in that the droplet-heating device is in the form of a laser, the laser beam of which heats the droplets in flight.

In accordance with yet a further feature of the invention, the deflection surface is coated with a liquid-repellent.

In accordance yet an added feature of the invention, the liquid repellent is formed of silicone or polytetrafluoroethylene, known by the trade name Teflon.

Thus, the deflection surface is provided with a liquid-repellent coating, particularly of silicone or Teflon. The coating has the surprising effect that the desired splitting of droplets takes place even if the surface temperature of the deflection surface or the temperature of the droplets has not been raised to a higher value. Rather, it may be sufficient to effect no increase in temperature whatsoever on the deflection plate and/or the droplets or to provide for just a small increase in temperature in the deflection surface and/or the droplet liquid. Nevertheless, the effect of elastic reflection is maintained, with the droplets being split, if desired. This feature, therefore, is particularly energy-saving.

In accordance with yet an additional feature of the invention, the deflection surface has a given defined roughness. In order to be able to effect the splitting of droplets in a desired manner, to determine the number of resulting chains of secondary droplets or, alternatively, to prevent the splitting of droplets, this feature is provided. The roughness is, therefore, also one of the aforementioned parameters.

In accordance with another feature of the invention, the deflection surface has a defined texturing. The type of texturing and also the geometry thereof has an effect upon the conditions when impact of the primary droplets occurs and permits the desired setting or adjustment, that is, splitting of the droplets or no splitting.

In accordance with a further feature of the invention, the ink-jet device includes means for selectively adjusting the relative velocity between the impacting droplets and the deflection surface. Thus, the relative velocity between the impacting droplets (primary droplets) and the deflection surface is selectively settable or adjustable. If there is a high relative velocity, a correspondingly high amount of energy is converted on impact, the energy having an effect upon splitting. If, due to a lower relative velocity, the energy is smaller, there is no splitting. A large amount of energy leads also to more than two subdroplets and, finally, it is also possible through the intermediary of the energy to determine the sizes of the volumes of the subdroplets.

In accordance with an added feature of the invention, the flying velocity of the droplets is selectively adjustable by means of the droplet-producing device.

In accordance with an additional feature of the invention, the ink-jet device includes a droplet-braking and/or accelerating device, the flying velocity of the droplets being selectively adjustable by means of one of the droplet-producing device and the droplet-braking and/or accelerating device.

The droplet-producing device preferably comprises a piezoelectric-crystal arrangement which, through suitable energization, undergoes changes in volume, as a result of which the droplets are ejected from a nozzle. Depending upon volume, travel and also rate of change, and so forth, it is thus possible to vary the flying velocity of the droplets. The aforementioned droplet-braking/accelerating device may, for example, be in the form of a device acting on the droplets in contact-free manner, the latter device emitting an airstream which brakes or accelerates the droplets. Furthermore, it is also possible to charge the droplets electrically and then to expose them to an accelerating field or to decelerate them by means of an electric field.

In accordance with still another feature of the invention, the deflection surface is movable by means of a driving device and oscillates, respectively, in or opposite to the direction of the trajectory so as to adjust the relative velocity.

In accordance with still a further feature of the invention, the deflection surface is movable by means of a driving device and oscillates, respectively, as a function of the droplet-ejection frequency of the droplet-producing device. In particular, the flying velocity of the droplets is selectively settable or adjustable by means of the droplet-producing device and/or by means of a droplet-braking and/or accelerating device. Thus, according to a further development of the invention, with the relative velocity set, the deflection surface is movable by means of a driving device in or opposite to the direction of the trajectory. Additionally or alternatively, it is also possible for the deflection surface to be in the form of an oscillatory system; that is, it is set in a state of oscillation by means of suitable devices, with the direction of the oscillating motion being selected in such a manner that at least one component thereof accords with the direction of the trajectory of the primary droplets, with the result that the oscillating motion, or a component thereof, is directed either opposite to the direction of flight of the primary droplets or, after a reversal of the oscillation, in the direction of the trajectory of the primary droplets. In this manner, the relative velocity between droplet and deflection surface is in one case greater and in the other case, after reversal of the oscillation, smaller. Depending upon the currently pertaining operating state when a droplet impacts the deflection surface, there will thus be a corresponding conversion of energy, with the result that either the droplet splits (into two or more subdroplets of equal or unequal volume) or the droplet does not split.

In accordance with still an added feature of the invention, the driving device is a deflection-surface swiveling device.

The movement of the deflection surface may be accomplished with the deflection surface itself being rigid and being moved in its entirety by means of the driving device, which may be effected in particular by means of a vibration

device, or with the deflection surface forming the aforementioned oscillatory system; that is, the deflection surface is excited by means of the driving device and is in an oscillating state, comparable to that of an eardrum when excited. Such an oscillating deflection surface exhibits locally different amplitudes. The amplitude in the peripheral regions of the deflection surface is smaller than in the center. The fact that the point of impact of the primary droplets is selective, through suitable deflection of the trajectory of the primary droplets, means that the velocity of the impacting droplets in relation to the deflection surface is selective.

In accordance with still a further feature of the invention, the driving device is a deflection-surface vibration device. Small, preferably periodic swiveling motions of the deflection surface result in motions in or opposite to the direction of the primary trajectory. In particular, the geometry is such that at least one component of the swiveling motion lies in or opposite to the direction of the primary trajectory. The farther the swiveling axis of the deflection surface is removed from the point of impact of the primary droplets, the greater is the distance moved and the deflection-surface velocity. Through synchronization of the droplet-ejection rate with the swiveling motion, it is possible, at the time of impact of the primary droplets, for the deflection plate to be moving in or opposite to the trajectory of the primary droplets, with the result that it is possible to set suitably higher or lower relative velocities and impact angles between the incoming droplet and the deflection surface.

Preferably, the droplets ejected by the droplet-producing device are primary droplets on the primary trajectory, and the droplets rebounding from the deflection surface are secondary droplets on at least one secondary trajectory. If the droplet is split into two parts, there are two secondary trajectories, which diverge from one another. If the droplet is split into more than two parts, there will be a corresponding number of secondary trajectories.

In accordance with still an additional feature of the invention, the trajectory is formed of a primary trajectory and at least one secondary trajectory, the droplets ejected by the droplet-producing device are primary droplets on the primary trajectory, and the droplets rebounding from the deflection surface are secondary droplets on the at least one secondary trajectory, and including a droplet-splitting electrode arrangement for applying an electric field to the secondary droplets disposed in the vicinity of the secondary trajectory, and a charging device for electrically charging the primary droplets.

In accordance with another feature of the invention, the droplet-splitting electrode arrangement is disposed near the reflection surface. Thus, there may be disposed in the region of the secondary trajectory, in particular near the deflection plate, a droplet-splitting electrode arrangement for applying an electric field to the secondary droplets. It is important, in this regard, that the primary droplets be electrically charged by means of a charging device. The charging device is situated preferably in the region between the droplet-producing device and the deflection surface. In accordance with a further feature of the invention, the charging device is a charging ring electrode situated in the primary trajectory. It is in particular in the form of a ring electrode in which the primary droplets are formed by constriction of the liquid jet. The charging of the electrode produces a charge in the developing droplet, with the current produced being drained through the liquid and the grounded ink reservoir. The electric potential is not lost through the impact of the primary droplet on the deflection surface. The parameters of the overall arrangement are set so that the droplet is not split by its impact with the deflection surface. It is, however, in a marginal state of "almost splitting"; that is, for example, its geometrical shape is no longer that of a droplet, but rather that of a "figure eight". By means of the aforementioned droplet-splitting electrode arrangement, it is possible to influence the respective secondary droplet just after impact in such a manner that it splits or does not split. This is accomplished by the selection of suitable potential at the electrodes of the droplet-splitting electrode arrangement. The arrangement is formed of two spaced-apart oppositely positioned electrodes, the secondary droplets flying through the thus formed gap. Preferably, one of the electrodes is integrated into the deflection surface and the other electrode is positioned opposite the deflection surface at a suitable distance from and, if required, at an angle to the other electrode. Splitting or non-splitting can be controlled depending upon the magnitude of the field strength of the droplet-splitting electrode arrangement and/or the polarity and/or the fact whether an electric field has been built up at all. If there is splitting, this is once again to the aforementioned extent, namely the number of secondary droplets and the specification of predeterminable volumes of the secondary droplets.

In accordance with an added feature of the invention, the ink-jet device includes a deflecting electrode arrangement situated in the primary trajectory and disposed between the charging device and the deflection surface. The charging device will have imparted an electric charge to the primary droplets as they move on the primary trajectory. As the droplets, on their further flight, then pass the deflecting electrode arrangement, if the deflecting electrode arrangement exhibits a defined electric field, then the primary droplets are influenced in their trajectory, thus correspondingly determining the point of impact on the deflection surface. Preferably, and this applies to all embodiments of the invention, the deflection surface extends at an acute angle with respect to the direction of the primary trajectory. Consequently, moving the point of impact of the primary droplets results in a change in the angles on impact (entry angle=exit angle), thus making it possible to exert an influence on the size of the droplets as they split, that is, on the size of the subdroplets.

In accordance with an additional feature of the invention, the ink-jet device includes a collecting element for respective secondary droplets, the collecting element being associated with the at least one secondary trajectory.

In particular, there is a split into, for example, two subdroplet streams, with one subdroplet stream being directed so that the subdroplets thereof enter a collecting reservoir, in which case those subdroplets are then not available for producing the image, but are recycled into the system. The remaining subdroplet stream flies past the collecting reservoir and reaches the recording medium. As mentioned hereinbefore, the volumes of the droplets of the stream can be set by means of the deflecting electrode arrangement; that is, depending upon the control of the deflecting electrode arrangement, the size of the droplets which reach the recording medium is preselective and results in corresponding inking of the recording medium. Alternatively or additionally, the aforementioned angular conditions may also be brought about in that the angle and/or position of the deflection surface is altered; that is, the setting of the volumes of the subdroplets is variable through this measure. Consequently, it is always possible to influence the direction of the secondary trajectories, with the result that the associated droplets either enter a collecting reservoir or, if desired, strike the recording medium.

In accordance with yet another feature of the invention, the ink-jet device includes a plurality of the deflection surfaces disposed so that a droplet formed by the droplet-producing device passes the plurality of deflection surfaces in succession. Thus, it is also possible for one or more deflecting electrode arrangements not to be disposed in the region of the primary trajectory, but in the region of the secondary trajectory/trajectories. According to a further feature, a droplet ejected by the droplet-producing device is fed consecutively to a plurality of deflection surfaces. As mentioned hereinbefore, there not only ensues a change in the trajectory, but this measure also makes it possible to split a primary droplet and then, in turn, to split the resulting secondary droplets when they impact on a following deflection surface, and so forth, it being possible ultimately in this manner to obtain very fine droplets. Secondary droplets which, in the course of the multiple splitting, are not to be used for the recording medium are always directed on trajectories which terminate in collecting reservoirs.

In accordance with yet a further feature of the invention, the ink-jet device includes a plurality of droplet-producing devices, and means for feeding droplets produced thereby, grouped and in focus, to the recording medium. Finally, it is advantageous if the droplets from a plurality of droplet-producing devices, grouped and focused, are fed to the recording medium. In this construction, it is possible for very large volumes of ink to be fed to the recording medium. In this connection, some droplet trajectories or at least one of the droplet trajectories may be provided with a deflection surface, with the result that, also when droplets are merged or fed to the same point on the recording medium, there is droplet splitting, at least in one of the droplet substreams. It is possible in this manner to set with great accuracy the desired total volume of the ink supplied and thus the production of gray levels.

In accordance with another aspect of the invention, there is provided an ink-jet process for producing an image on a recording medium, which comprises ejecting droplets along a trajectory, controlling the trajectory of the droplets with a droplet-controlling device formed as a deflection surface and disposed so that respective droplets impact thereon and rebound to continue the flight thereof, the respective droplets being splittable into at least two subdroplets as a function of selected parameters, and selecting parameters so that the respective droplets are split into at least two subdroplets.

In accordance with another mode of the process according to the invention, the parameters are selected from the group consisting of the surface characteristics of the deflection surface, the material of the deflection surface, the temperature of the deflection surface, the temperature of the droplets, the relative velocity between droplet and deflection surface and the angle of impact of the droplets on the deflection surface.

In accordance with a further mode of the invention, the ink-jet process includes splitting the subdroplets at least another time by colliding the subdroplets with a further deflection surface. It is thereby possible to obtain very small droplet volumes.

In accordance with a concomitant mode of the invention, the ink-jet process includes forming a plurality of droplet streams having, in at least one stream thereof, droplets which have been split, and feeding streams of respective droplets and/or subdroplets, in grouped fashion, to the recording medium. It is thereby possible to produce an image dot with a particularly fine gradation of gray.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in an ink-jet device and a method of operation thereof, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which: drawings, in which:

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a diagrammatic and schematic view of a first embodiment of an ink-jet device constructed in accordance with the invention;

FIG. **2** is an enlarged fragmentary view of FIG. **1** showing a second embodiment of the ink-jet device according to the invention;

FIG. **3** is a fragmentary view of a third embodiment of the ink-jet device;

FIG. **4** is a slightly enlarged view of FIG. **1** showing a fourth embodiment of the ink-jet device;

FIG. **5** is a diagrammatic and schematic view of a fifth embodiment of the ink-jet device wherein multiple splitting of the ink stream is performed;

FIG. **6** is a diagrammatic view of a seventh embodiment of the ink-jet device wherein a plurality of ink streams are grouped;

FIG. **7** is an enlarged representation of a collision of a chain of droplets with a deflection surface;

FIG. **8** is another view of FIG. **7**, however, showing the impacting droplets being split; and

FIG. **9** is yet another view of FIG. **7**, however, wherein no splitting of the droplets has yet occurred.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and, first, particularly to FIG. **1** thereof, there is shown therein an ink-jet device **1**, including a droplet-producing device **2** which is supplied with ink from ink reservoirs **3** and **4** via lines **5** by means of a pump **6**. The droplet-producing device **2** has a nozzle from which a liquid jet **8** of the ink is ejected. Individual primary droplets **7** are formed from the liquid jet **8** in a ring electrode **13** of a charging device **11**, and move along a trajectory **10** forming a primary trajectory **9**.

Situated at the end of the primary trajectory **9** is a deflection element **15**, which has a deflection surface **16**. The deflection surface **16** is flat in form and extends at an acute angle alpha with respect to the direction of the primary trajectory **9**.

During the flight of the droplets **7** on the primary trajectory **9**, they strike the inclined deflection surface **16** from which they rebound and continue their flight. As a result of the impact, each primary droplet **7** is split into two secondary droplets **17** and **18**. The individual secondary droplets **17** and **18** form corresponding secondary chains of droplets. The secondary droplets **17** and **18** move on secondary

trajectories **19** and **20**. At the ends of the secondary trajectories **19** and **20**, the respective secondary droplets **17** and **18** strike a recording medium **21**, such as, paper, for example, which moves in the direction of the arrow **22**. The secondary droplets **17** and **18** produce an image on the recording medium **21**.

Each secondary trajectory **19** and **20**, respectively, is associated with a deflecting electrode arrangement **23** and **24**, respectively. Each deflecting electrode arrangement **23** has two plate electrodes, between which the respective secondary trajectory **19** or **20** extends. The ink reservoir **23**, formed as a collecting reservoir **25**, is situated to the side of the secondary trajectory **20** and the ink reservoir **4**, which is similarly formed as a collecting reservoir **26**, is situated to the side of the secondary trajectory **19**.

Preferably, the deflection surface **16** is heated by means of a non-illustrated heating device. A consequence thereof is that primary droplets **7** impacting thereon are elastically reflected on a vapor cushion. Simultaneously, the aforementioned splitting of the droplets occurs.

The primary droplets **7** passing the charging device **11** are electrically charged due to the existence of an electric field therein; that is, they possess an electric charge, which they retain, even after droplet splitting. As the thus charged secondary droplets **17** and **18**, respectively, formed from the primary droplets **7**, then pass the respective deflecting electrode arrangements **23** and **24**, and if the deflecting electrode arrangements **23** and **24** generate defined electric fields, a deflection results, i.e., the relevant secondary droplets **17** and **18** are deflected into the ink reservoirs **4** and **3**, respectively. Due to the fact that the relatively large-sized primary droplets **7** are broken down into secondary droplets **17** and **18**, respectively, the relative volumes of the secondary droplets **17** and **18** being capable of being selected by means of suitable parameters, such as the impact velocity on the deflection surface **16**, it is possible to apply a desired size of droplet to the recording medium which, depending upon the size of droplet selected, results in a corresponding gray level with correspondingly desired resolution.

FIG. **2** shows a detail of another embodiment of the ink-jet device **1** according to the invention. From the droplet-producing device **2**, the primary droplets **7** reach the deflection surface **16**, which oscillates. The oscillations are produced by means of a suitable non-illustrated driving device. The oscillating movement is indicated by the somewhat elliptical form shown in broken lines and the double-headed arrow associated therewith. The somewhat elliptical form shows that the deflection or oscillation amplitude in the center of the deflection surface **16** is greater than at the edges. Consequently, a corresponding velocity profile is also provided. The velocity of the primary droplets **7** is identified as V_1; the velocity of the oscillating deflection surface **16** is identified as V_2. When the velocity V_2 is broken down into its components, one of the components extending in or opposite to the direction of the primary trajectory **9**, then it becomes apparent that, depending upon the instant of impact of a primary droplet **7** on the oscillating deflection surface **16**, there is either a lower relative velocity or a higher relative velocity on impact. The relative velocity or impact velocity is particularly great when the deflection surface **16** oscillates towards the incoming primary droplets **7**. If the deflection surface **16** should just happens to be oscillating in the direction of the primary trajectory, then there is a lower relative velocity. Depending upon the respective adjustable relative velocity, which requires the oscillations of the deflecting surface **16** to be synchronized with the droplet-ejection frequency, it is possible to obtain a reflection at the deflection surface **16** with which either a droplet splitting occurs or no droplet splitting occurs.

FIG. **3** illustrates a detail of another embodiment of the ink-jet device according to the invention. Just as with regard to FIG. **2**, so too with regard to the embodiment shown in FIG. **3**, reference is made to component parts which have been omitted from the last-mentioned figure, but are clearly visible in FIG. **1**, and indeed constitute component parts of all of the embodiments. It is apparent from FIG. **3** that a charging device **11** is disposed in the region of the primary trajectory **9** and has a ring electrode **13**. The embodiment of FIG. **3** has as a special feature that a droplet-splitting electrode arrangement **27** is disposed in the starting or initial region of the secondary trajectories **19** and **20**. The droplet-splitting electrode arrangement **27** includes two spaced-apart, oppositely positioned plate electrodes **28** and **29**, which are connected to a corresponding control voltage output of a non-illustrated control system. The plate electrode **28** is integrated into the deflection surface **16**; the surface of the plate electrode **20** is disposed in alignment with the remaining surface portion of the deflection surface **16**. The further plate electrode **29**, disposed opposite and at a spaced distance from the plate electrode **28**, extends in a manner that the electrode plane thereof is preferably at an angle with respect to the plane of the plate electrode **28**, and being inclined thereto so that, as viewed in the direction of the secondary trajectories **19** and **20**, a diverging arrangement is formed. The two secondary trajectories **19** and **20** extend between the two plate electrodes **28** and **29**. Further provided in the course of the secondary trajectory **19** is a deflecting electrode arrangement **23**, which is formed of two plate electrodes, between which the secondary trajectory **19** extends.

During the operation of the ink-jet device shown in FIG. **3**, the oncoming primary droplets **7** are charged by means of the charging device **11**. Thereafter, in the impact region **30**, the droplets **7** are caused to impact with the deflection surface **16**, which extends obliquely with respect to the primary trajectory **9**. The deflection surface **16** may, for example, be heated, or may be formed of a liquid-repellent material, such as Teflon, for example. It is necessary to ensure that there is no wetting of the deflection surface **16**, but that the primary droplets **7** be elastically reflected. As viewed in the direction of the secondary trajectories **19** and **20**, the impact region **30** is followed by the plate electrode **28** in the region of the deflection surface **16**. Consequently, the droplet-splitting electrode arrangement is located downstream of the impact region **30**. Accordingly, the droplet-splitting electrode arrangement acts upon droplets that have already been reflected from the deflection surface **16**. The arrangement is such that, through the setting of defined parameters, the reflected droplets do not split. If those parameters are altered, however, which can be effected by exposing the reflected droplets to an electric field from the droplet-splitting electrode arrangement, then the droplets may be split, for example into two subdroplets. This means that, through appropriate control of the droplet-splitting electrode arrangement, it is possible to cause droplet splitting to occur or not to occur, selectively. Consequently, in the case of non-splitting, large droplet volumes can be fed to the recording medium or, alternatively, depending upon the parameters, a droplet splitting takes place, with the individual volumes of the subdroplets also being controllable by means of the parameters. It is thus possible accurately to select the desired droplet volume for both streams of subdroplets. By means of the deflecting electrode arrangement **23**, it is possible for the subdroplet stream on the secondary

trajectory **19** to be influenced in such a manner that it either reaches the recording medium or, alternatively, enters an ink reservoir (not shown in FIG. 3).

FIG. 4 shows a further embodiment of the ink-jet device **1**, which differs essentially from the embodiment in FIG. **1** in that a deflecting electrode arrangement **23** is disposed between the charging device **11** and the deflection surface **16**. The primary droplets **7** fed from the droplet-producing device **2** are created in the charging ring electrode **13**, where they are provided with a corresponding electric potential. They then fly through the deflecting electrode arrangement **23**, by means of which they can be controlled in such a manner that different points of impact are obtained on the deflection surface **16**. This, in turn, has an effect upon the impact angle and also upon the velocity at which impact takes place on the deflection surface **16**. This potential for effecting variations makes it possible to exert an influence upon the individual volumes of the subdroplets forming due to the impact thereof on the deflection surface **16**. It is apparent from FIG. 4 that the secondary droplets **17** are fed to the recording medium **21**, while the secondary droplets **18** land in an ink reservoir **4**. Because the volume of the secondary droplets **17** can be set by means of the deflecting electrode arrangement **23**, it is possible to adjust the required gray level, in a desired manner.

Alternatively, in FIG. **4**, a double-headed arrow **311** is shown in the region of the impact surface **16**. The double-headed arrow **311** is intended to indicate that it is possible to alter the position of the deflection element **15**. A suitable non-illustrated device is provided for this purpose. Through such change in position, also, it is possible to exert an influence upon the volumes of the subdroplets. This measure may be implemented alone or in combination with the aforementioned deflecting electrode arrangement **23**.

FIG. **5** shows an embodiment of the ink-jet device wherein multiple droplet splitting occurs. Several deflection surfaces **16** are provided. The deflection surfaces **16** are situated inside a housing **31** which is formed with a bottom opening **32**. An inlet opening **34** is formed at the top **33** of the housing **31**. The bottom region of the housing **31**, situated to either side of the bottom opening **32**, is trough-like in form and serves as an ink reservoir **3**. The deflection surfaces **16** are formed on brackets **35**, which are attached to side walls of the housing **31**.

The ink reservoir **3** communicates with a pump **6** and a droplet-producing device **2**. The primary droplets **7** supplied from the droplet-producing device **2** fly through the inlet opening **34**, where they strike a deflection surface **16'**, as a result of which they split into two subdroplet streams **36** and **37**. The subdroplet stream **37** lands on an inclined drain surface **380** on the bracket **35**, from which it drips into the ink reservoir **3**. The associated subdroplets, therefore, are not fed to the recording medium **21**. Conversely, the subdroplet stream **36** strikes a further deflection surface **16"** on the end face of the bracket **35** and is, in turn, split into two subdroplet streams **38** and **39**. The subdroplet stream **38** passes through an opening formed in the bracket **35** and enters the ink reservoir **3**. The subdroplet stream **39** strikes the deflection surface **16** formed on the end face of the lower-lying bracket **35**, and is, in turn, split thereat into two subdroplet streams **40** and **41**. The droplets of the subdroplet stream **40** enter the ink reservoir **3**. The droplets of the subdroplet stream **41** fly through the bottom opening **32**, being deflected once again on a deflection surface **16'''**; in this case, however, there is no droplet splitting. It is conceivable, however, in this case, also, as yet another embodiment, to perform a droplet splitting. This is the case when it is desired that two droplet streams should strike the recording medium **21**.

It becomes apparent from the foregoing description that the relatively large-sized primary droplets **7** are converted, through multiple droplet splitting, into very fine droplets, which then reach the recording medium. It is possible, therefore, to achieve a very fine resolution due to the fine ink droplets. Conversely, however, it is also possible, by means of the device according to the invention, to make the primary droplets comparatively large in size, which offers no problem from the point of view of the process, without having to forego the fine resolution on the recording medium **21**.

In the embodiment shown in FIG. **6**, the objective is to produce the largest possible number of gray levels for each image dot on the recording medium **21**. Provided for this purpose is a plurality of droplet-producing devices **2**, which feed the primary droplets **7** thereof to deflection surfaces **16**, which are disposed in such a manner that the reflected droplets enter trajectories which converge with respect to one another, as a result of which the droplets reach the recording medium **21** in focused form. Provision can be made for droplet splitting to occur at least upon the collision of the primary droplets from one of the droplet-producing devices **2**, due to which it is possible in general to exert an influence upon the overall volume of ink and thus upon the gray-level value of the image dot.

Further derived from FIG. **6** is that, disposed between the furthest-downstream deflection surface **16**/deflection surfaces **16**, respectively, is a deflecting electrode arrangement **23** by means of which the secondary-droplet streams, or at least some of the secondary-droplet streams, can be controlled in such a manner that the associated droplets enter an ink reservoir **3** and do not reach the recording medium **21**. Likewise provided in the embodiment shown in FIG. **6** are charging devices **11**, which impart a charge to the primary droplets **7** formed from the liquid jet; that is, the primary droplets **7** are electrically charged, with the result that they can be controlled in their trajectory by means of the deflecting electrode arrangement **23**.

FIG. **7** illustrates the elastic impact of the primary droplets on the deflection surface **16**. Arriving from the left-hand side of the figure, the primary droplets **7** strike the deflection surface **16**, thereby undergoing deformation, and are then reflected and rebound from the deflection surface **16** without any droplet splitting. Conversely, in FIG. **8**, the aforementioned parameters are set differently, with the result that, after the primary droplets **7** have impacted the deflection surface **16**, they are split into two substreams. It is clearly discernible that the volumes of the individual secondary-droplet streams are of different magnitudes.

FIG. **9** represents a collision process wherein the droplets just fail to split. The primary droplets impacting the deflection surface **16**, undergo extreme deformation into approximately figure eight-shaped forms which, after collision, contract again and, during further flight thereof, regain their droplet shape. Under such a condition, if one were, for example, to increase the velocity of the primary droplets just slightly or expose the secondary droplets to an electric field in the region of the collision zone, then droplet splitting would occur. Electrical control over the droplets requires that the primary droplets **7** should be electrically charged, which is possible to effect by means of a charging electrode arrangement.

We claim:

1. Ink-jet device for producing an image on a recording medium, comprising a droplet-producing device for ejecting

droplets along a trajectory, and a droplet-controlling device for controlling the trajectory of the droplets, said droplet-controlling device being formed as a deflection surface, said deflection surface being disposed so that respective droplets impacting thereon are split into at least two subdroplets.

2. Ink-jet device according to claim 1, wherein the droplets impact at a droplet-impact given region of said deflection surface, and including a heating device for heating said droplet-impact region of said deflection surface.

3. Ink-jet device according to claim 1, wherein said droplet-producing device includes a droplet-heating device.

4. Ink-jet device according to claim 3, wherein the droplets ejected by said droplet-producing device are heated to a selective temperature by said droplet-heating device.

5. Ink-jet device according to claim 3, wherein said droplet-heating device is disposed so as to be able to act upon the droplets while they are in flight.

6. Ink-jet device according to claim 5, wherein said droplet-heating device is formed as a laser for heating the droplets in flight.

7. Ink-jet device according to claim 1, wherein said deflection surface is coated with a liquid repellent.

8. Ink-jet device according to claim 7, wherein said liquid repellent is formed of silicone or polytetrafluoroethylene.

9. Ink-jet device according to claim 1, wherein said deflection surface has a given defined roughness.

10. Ink-jet device according to claim 1, wherein said deflection surface has a defined texturing.

11. Ink-jet device according to claim 1, including means for selectively adjusting a relative velocity between the impacting droplets and said deflection surface.

12. Ink-jet device according to claim 11, wherein said deflection surface is movable by means of a driving device and oscillates, respectively, in or opposite to the direction of the trajectory so as to adjust the relative velocity.

13. Ink-jet device according to claim 12, wherein said driving device is a vibration device.

14. Ink-jet device according to claim 12, wherein said driving device is a deflection-surface swiveling device.

15. Ink-jet device according to claim 11, wherein said deflection surface is movable by means of a driving device and oscillates, respectively, as a function of the droplet-ejection frequency of the droplet-producing device.

16. Ink-jet device according to claim 1, wherein a flying velocity of the droplets is selectively adjustable by means of said droplet-producing device.

17. Ink-jet device according to claim 1, including a droplet-braking and/or accelerating device, the flying velocity of the droplets being selectively adjustable by means of one of said droplet-producing device and said droplet-braking and/or accelerating device.

18. Ink-jet device according to claim 1, wherein the trajectory is formed of a primary trajectory and at least one secondary trajectory, the droplets ejected by said droplet-producing device are primary droplets on the primary trajectory, and the droplets rebounding from the deflection surface are secondary droplets on the at least one secondary trajectory, and including a droplet splitting electrode arrangement for applying an electric field to the secondary droplets disposed in the vicinity of the secondary trajectory, and a charging device for electrically charging the primary droplets.

19. Ink-jet device according to claim 18, wherein said droplet-splitting electrode arrangement is disposed near said deflection surface.

20. Ink-jet device according to claim 18, wherein said charging device is a charging ring electrode situated in the primary trajectory.

21. Ink-jet device according to claim 18, including a deflecting electrode arrangement situated in the primary trajectory and disposed between said charging device and said deflection surface.

22. Ink-jet device according to claim 18, including a collecting element for respective secondary droplets, said collecting element being associated with said at least one secondary trajectory.

23. Ink-jet device according to claim 1, wherein said deflection surface is one of a plurality of deflection surfaces disposed so that a droplet formed by said droplet-producing device passes said plurality of deflection surfaces in succession.

24. Ink-jet device according to claim 1, including a plurality of droplet-producing devices, and means for feeding droplets produced thereby, grouped and in focus, to the recording medium.

25. Ink-jet process for producing an image on a recording medium, which comprises the steps of ejecting droplets along a trajectory, controlling the trajectory of the droplets with a droplet-controlling device formed as a deflection surface and disposed so that respective droplets impact thereon and rebound to continue the flight thereof, the respective droplets being splittable into at least two subdroplets as a function of selected parameters, and selecting parameters so that the respective droplets are split into at least two subdroplets.

26. Ink-jet process according to claim 25, wherein the parameters are selected from the group consisting of the surface characteristics of the deflection surface, the material of the deflection surface, the temperature of the deflection surface, the temperature of the droplets, the relative velocity between droplet and deflection surface and the angle of impact of the droplets on the deflection surface.

27. Ink-jet process according to claim 25, which includes splitting the subdroplets at least another time by colliding the subdroplets with a further deflection surface.

28. Ink-jet process according to claim 25, which includes forming a plurality of droplet streams having, in at least one thereof, droplets which have been split, and feeding streams of respective droplets and/or subdroplets, in grouped fashion, to the recording medium.

* * * * *

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Stilli

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(45) **Date of Patent:** **Mar. 26, 2002**

(54) **SLOT NOZZLE FOR SPRAYING A CONTINUOUS CASTING PRODUCT WITH A COOLING LIQUID**

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(73) Assignee: **Concast Standard AG**, Zurich (CH)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/571,106**

(22) Filed: **May 15, 2000**

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(30) **Foreign Application Priority Data**

Nov. 14, 1997 (CH) 2639/97

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(52) **U.S. Cl.** **239/590**; 239/592; 239/597
(58) **Field of Search** 239/589, 590, 239/590.5, 592, 597, 599, 601, 398, 433, 434.5, 499, 463, 543, 429

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(57) **ABSTRACT**

The spray nozzle comprises a mixing chamber into which a liquid, forming a first and a second liquid stream, can flow through two inlet openings and which comprises an outlet opening, disposed downstream, for a spray jet. A mixing chamber wall acts as a guide surface for the liquid streams and is shaped at the outlet opening such that the liquid streams meet at an angle at the outlet opening and then form the spray jet. Given an angle of impact of approximately 90°, this spraying process delivers droplets with a high level of kinetic energy and a broad uniform fan-out of the droplet paths. Large areas can therefore be uniformly sprayed with the spray nozzle from a considerable distance.

15 Claims, 3 Drawing Sheets

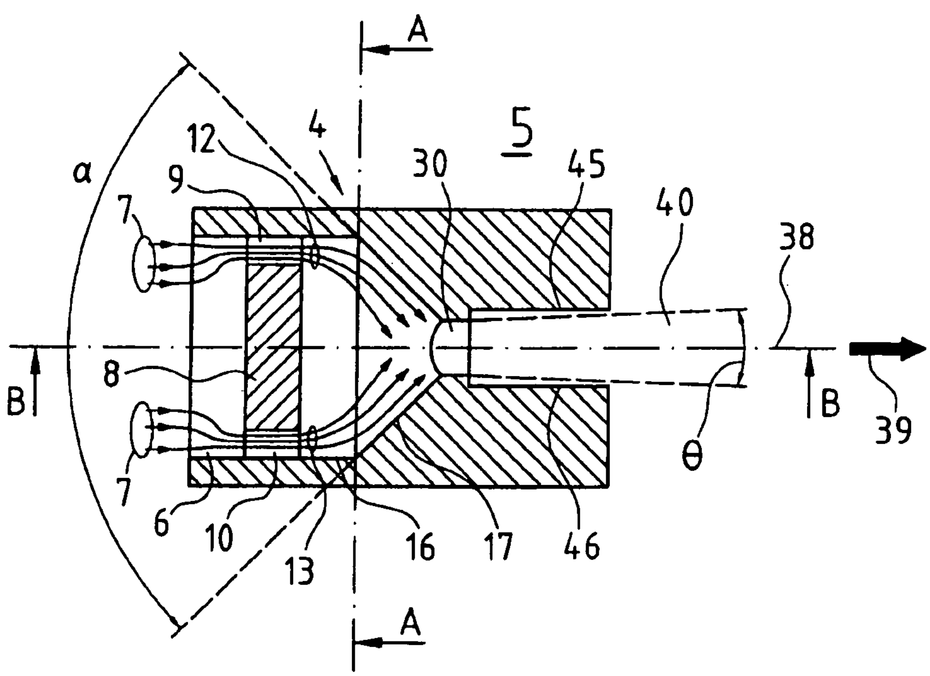

Fig. 1A

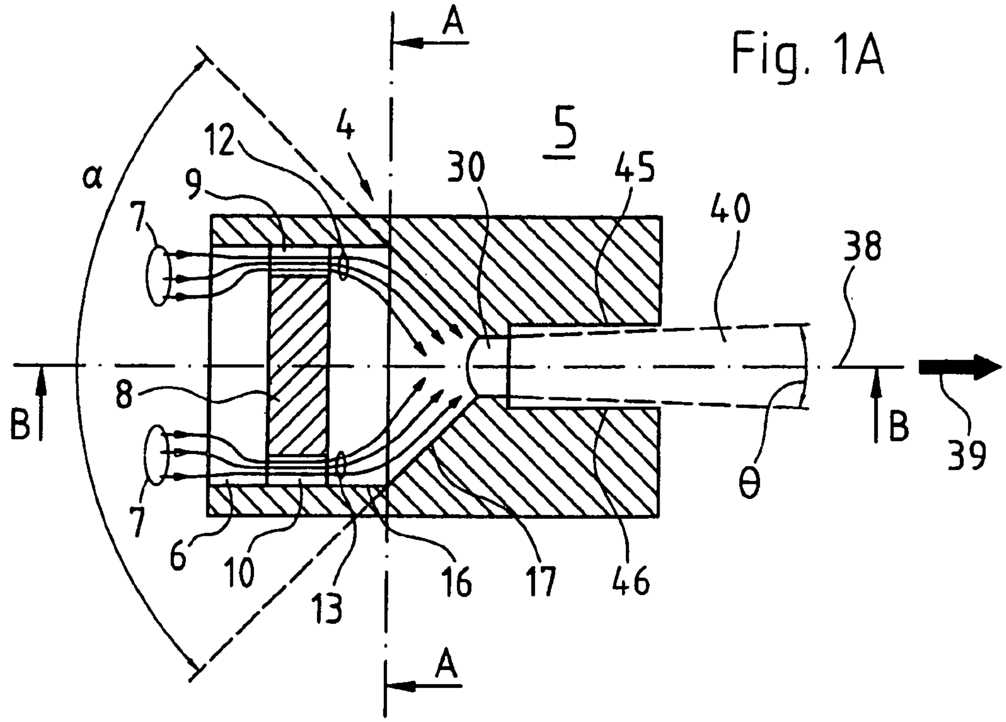
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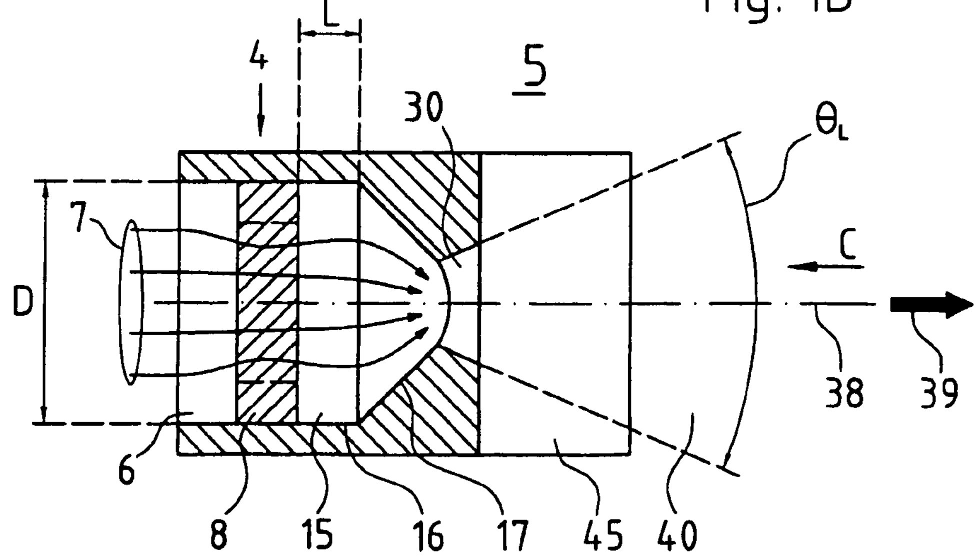
Fig. 1B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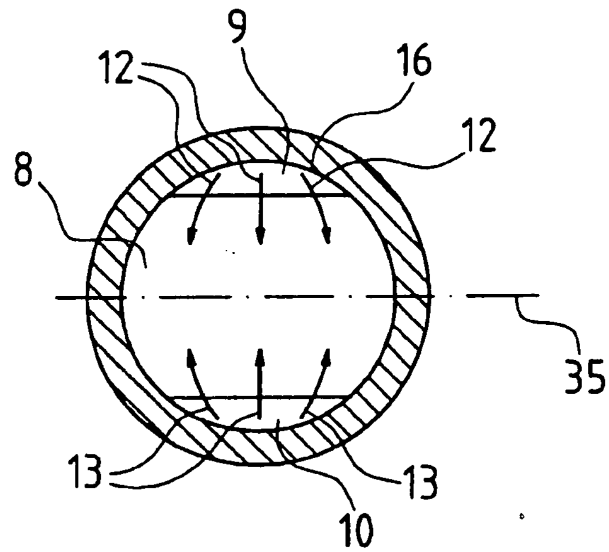

Fig. 2A

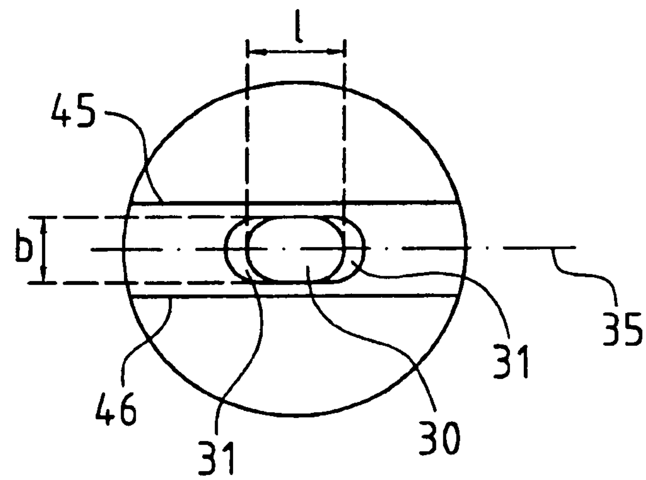

Fig. 2B

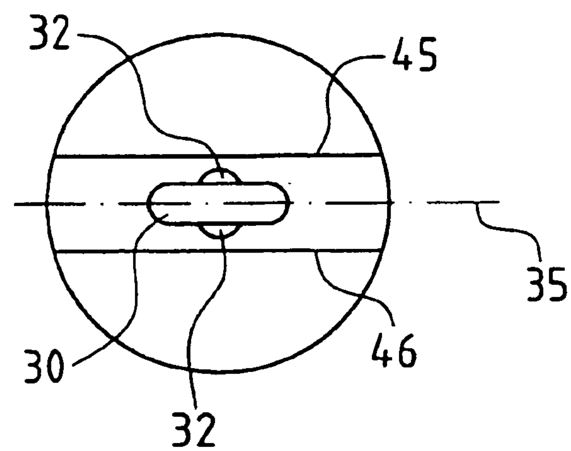

Fig. 2C

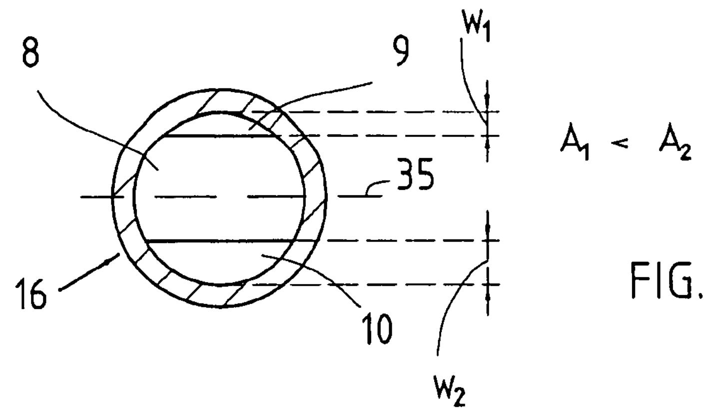

FIG. 3A

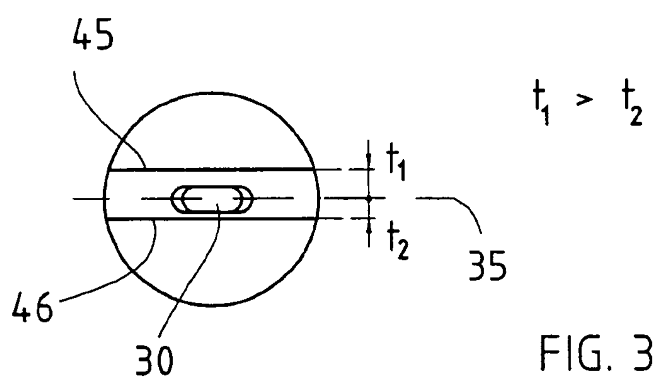

FIG. 3B

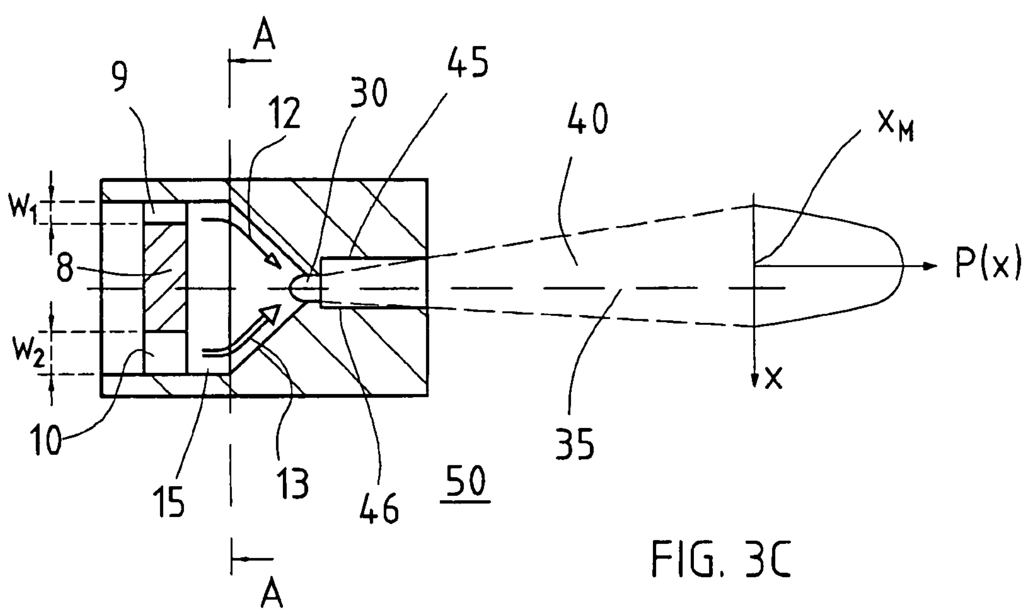

FIG. 3C

SLOT NOZZLE FOR SPRAYING A CONTINUOUS CASTING PRODUCT WITH A COOLING LIQUID

This is a continuation of international application Ser. No. PCT/EP98107069 filed Nov. 5, 1998, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

The invention relates to a spray nozzle for spraying a continuous casting product with a cooling liquid according to the preamble of claim **1**.

BACKGROUND OF THE INVENTION

As is known, in a continuous casting process, in particular for the continuous casting of steel, cooling of a metal melt in a continuous casting mould results in a continuous casting product which is continuously drawn out of the mould in the form of a strand whose surface is constituted by a solidified crust and which still has a liquid core of metal melt. After leaving the mould, the strand is conveyed through a secondary cooling zone in which it is sprayed with a coolant, generally water, in order to continue removing heat from it until it has completely solidified and bring it to the temperature desired for subsequent processing.

As secondary cooling directly causes the strand to solidify or influences its solidification, the secondary cooling process and the devices required to carry it out have a decisive effect on the quality of the end products. The components used to disperse the coolant, in particular the spray nozzles, are of particular importance.

The various parameters which characterise the secondary cooling process affect the solidification of the strand in different ways and—depending on the practice—must be optimised according to different criteria.

Particularly important factors are the secondary cooling intensity, which determines the speed of the strand shell growth and which is set to be more or less "harsh" or "gengentle", depending on the practice, and the spatial distribution of the coolant application density, which should be as homogeneous as possible in order to ensure that the strand shell growth is as homogeneous as possible.

The spray nozzles used in a secondary cooling section to atomise a coolant are usually optimised with regard to the required standards of secondary cooling intensity and homogeneity of the coolant application. The kinetic energy of the cooling liquid droplets applied by spraying and, in particular, the coolant application density are in this respect determining factors for the secondary cooling intensity. The homogeneity of the coolant application density is not just determined by the homogeneity of the droplet dispersion in the spray jet produced by an individual spray nozzle. The angular distribution of the droplet paths is also relevant to the homogeneity of the coolant application density. Namely, the angular distribution determines the shape and the size of the area on a strand which can be sprayed with a spray jet. However a large number of spray nozzles are required in a secondary cooling zone in order to cover with coolant the entire area of a strand which is to be cooled. The spray jets of the individual nozzles are therefore superimposed accordingly. The angular distribution of the droplet paths of an individual spray jet is consequently a decisive factor for the homogeneity of the coolant application density when superimposing a large number of spray jets.

The known full cone nozzles deliver spray jets with a conical angular distribution of the droplet paths. Because of their conical shape, the spray jets of a plurality of full cone nozzles are unable to perfectly cover large areas for spraying; the superimposition of a plurality of spray jets results in a highly inhomogeneous coolant application density. A spray nozzle having all the features of the preamble of claim **1** is known from U.S. Pat. No. 3 072 346. This spray nozzle has a nozzle body with a mixing chamber which is rotationally symmetrical about the longitudinal axis of the nozzle body, into which chamber a liquid, forming a first and a second liquid stream, can flow through two inlet openings and which is provided with an outlet opening, disposed downstream, for a spray jet. Apart from the formation of the outlet opening, this nozzle has essential features of a known type of full cone nozzle: The two inlet openings are integrated into a guide structure for the liquid streams entering the mixing chamber such that a velocity component is imparted to the liquid streams tangentially to the mixing chamber wall as they enter the mixing chamber in addition to a velocity component in the direction of the outlet opening. This tangential velocity component causes the two liquid streams to combine after entering the mixing chamber to form one liquid stream which is directed at the outlet opening and which exhibits a vortex about the longitudinal axis of the nozzle body. Although the spray nozzle which is described in U.S. Pat. No. 3 072 346 has a round outlet opening—like a conventional full cone nozzle—, this outlet opening is widened like a funnel on the outlet side such that the emerging spray jet is distorted in the direction of the diagonals of a square. Because the outlet opening is formed in this way, the nozzle delivers a spray jet with an approximately square droplet dispersion related to a plane perpendicular to the longitudinal axis of the nozzle body.

One disadvantage of this spray nozzle is that, because of the vortex which is imposed, the form of the droplet dispersion of the spray jet is distorted to an increasing degree as the infeed pressure of the liquid increases. It is therefore impossible to comply with the standards required in terms of homogeneity of the coolant application density in a secondary cooling section with a nozzle of this kind.

A further disadvantage of this nozzle lies in the fact that its spray jet only has an approximately square droplet dispersion in one spray plane, which may not be very far away from the outlet opening, typically not more than 20 cm. Because of the short operating distance, a large number of spray nozzles of this kind are required to spray large areas with a sufficient degree of homogeneity.

BACKGROUND OF THE PRIOR ART

A flat-jet nozzle is described in U.S. Pat. No. 4 988 043. It comprises a passage for the liquid to be atomised with an outlet slot for the spray jet. The spray jet is fanned out over a wide angular range in the slot direction, whereas it hardly widens transversely to the longitudinal direction of the slot as the distance from the outlet slot increases. The quasi one-dimensional fan-out results in a flat spray jet. On account of the small extent of the spray jet transversely to the outlet slot, the process of spraying relatively large rectangular areas entails complications, whether because a large number of these flat-spray nozzles must be used or because a single flat-spray nozzle must be moved in order to cover a relatively large area with its spray jet.

OBJECT OF THE INVENTION

Taking the inadequacies of the known spray nozzles as a starting point, the object of the invention is to provide a spray nozzle which is suitable for use in a secondary cooling

section of a continuous casting plant and for this purpose enables the largest possible area to be sprayed as homogeneously as possible with liquid droplets with the greatest possible kinetic energy from the greatest possible distance.

This object is achieved by a spray nozzle having the features of claim 1.

The spray nozzle according to the invention comprises a mixing chamber into which a liquid, forming a first and a second liquid stream, can flow through two inlet openings and which comprises an outlet opening, disposed downstream, for a spray jet, wherein at least one mixing chamber wall is formed as a guide surface for the liquid streams and is shaped at the outlet opening such that the liquid streams meet at an angle at or directly before the outlet opening and then form the spray jet. Because the two liquid streams are directed at the outlet opening and collide at the outlet opening, relatively large liquid droplets are produced which—related to the infeed pressure at the inlet openings—can leave the outlet opening with a relatively high level of kinetic energy. Energy losses due to vortex formation in the mixing chamber are largely prevented. The high level of kinetic energy allows an area to be sprayed from a considerable working distance. The atomisation of the two liquid streams permits a large spread of the directions of propagation of the droplets and therefore a wide fan-out of the spray jet emerging from the outlet opening. In this respect the droplets which are dispersed transversely to the direction of propagation of the liquid streams in particular play an important part in the fan-out of the spray jet. As the propagation of the liquid streams in the mixing chamber is substantially determined by the geometry of the mixing chamber, the infeed pressure can be varied over a relatively broad range without any substantial change in the fan-out of the spray jet.

In this connection the cross section of an inlet opening is basically understood to mean a section transverse to the respective liquid stream in the inlet opening, and the cross section of the outlet opening a section transverse to the spray jet.

The properties of a spray jet produced with the spray nozzle according to the invention depend substantially on the angle of impact at which the liquid streams meet at or directly before the outlet opening. An angle of impact in a range between 60° and 130°, preferably between 80° and 100°, is advantageous. This creates the conditions for producing liquid droplets which leave the outlet opening with a particularly high level of kinetic energy and form a spray jet which is distinguished by the fact that the droplets disperse in a particularly uniform manner over a particularly large solid angle about a mean direction of propagation.

The spray nozzle according to the invention has a slot as the outlet opening. If its cross-sectional area transverse to the direction of propagation of the spray jet is appropriately shaped, an outlet slot offers the possibility of spraying a rectangular area, for example. The long sides of the rectangular area for spraying are in this case substantially parallel to the direction of the longitudinal extent of the slot. The angular range over which the spray jet fans out in the direction of the longitudinal extent of the outlet slot increases with the length of the slot. This effect is due to the fact that the angular range in which droplets can leave the interaction zone of the two liquid streams at the outlet opening through the outlet slot increases in the direction of the longitudinal extent of the slot with the length f the outlet slot.

In one embodiment of the spray nozzle according to the invention the mixing chamber has a taper at the outlet opening with an opening angle at the outlet opening of between 60° and 130°, preferably between 80° and 100°. The taper forms the part of the guide surface for the liquid streams which determines the angle of impact. The taper brings together the two liquid streams at the outlet opening at an angle of impact which corresponds to the opening angle of the taper. The droplets produced at the outlet opening when the two liquid streams interact have a particularly large velocity component in the direction of the bisector of the opening angle of the taper. This direction corresponds to the mean direction of propagation of the droplets which can leave the outlet opening. Depending on its shape, the outlet opening also provides an exit for droplets whose paths are scattered over a solid angle about the mean direction of propagation. The taper may be conical, for example.

A number of further developments of the spray nozzle according to the invention have further features which, either alone and/or combined with one another, afford the condition for a homogeneous droplet dispersion over an area for spraying. In order to achieve a homogeneous droplet dispersion, it is advantageous for the outlet opening and the mixing chamber to have a common plane of symmetry. On this assumption, the two liquid streams are symmetrical with respect to the plane of symmetry. Droplets whose paths extend symmetrically to the plane of symmetry can therefore be produced. A spray nozzle whose outlet opening is formed as a slot will produce a particularly homogeneous droplet dispersion if the inlet openings in each case have a cross-sectional area of elongate shape and the directions of their longitudinal extent are in each case substantially parallel to the direction of the longitudinal extent of the outlet slot. In this case the two liquid streams are in a sense "preshaped" and adapted to the outlet slot at the inlet openings so that even at the inlet openings the lines of equal flow velocity—related to a plane transverse to the respective liquid stream—have the same or approximately the same shape as the cross-sectional area of the outlet opening (transversely to the central direction of propagation of the liquid droplets).

Another embodiment of the spray nozzle according to the invention has an outlet slot and is formed such that the mixing chamber and the outlet slot have a common plane of symmetry, wherein the longitudinal direction of the outlet slot lies in the plane of symmetry and the inlet openings are disposed on different sides of the plane of symmetry. In this case the spray jet is fanned out particularly widely in the plane of symmetry, i.e. in the longitudinal direction of the outlet slot. The droplet dispersion additionally becomes particularly homogeneous if—as in the previously discussed embodiment—the inlet openings have a cross-sectional area of elongate shape and the directions of their longitudinal extent are substantially parallel to the plane of symmetry. A particularly uniform droplet dispersion is achieved if the ratio of the sum of the two cross-sectional areas of the inlet openings to the cross-sectional area of the outlet opening is between 1.5 and 2, preferably between 1.6 and 1.8.

Another embodiment of the spray nozzle is distinguished by the fact that the mixing chamber has a taper of the above-mentioned type at the outlet opening and a cylindrical segment between the taper and the inlet openings. The cylindrical segment acts as a side wall which bounds the liquid streams. The length of the cylindrical element influences the way in which the two liquid streams intermix at the outlet opening and the efficiency with which the liquid streams are converted into droplets which leave the outlet opening unimpeded. The length of the cylindrical segment may be optimised accordingly. Additionally, it is advanta-

geous if the inlet openings open out at the side wall of the mixing chamber. Then the energy losses due to unwanted vortex formation in the mixing chamber are particularly low and the production of the spray jet is particularly efficient.

A spray nozzle with a mixing chamber of a particularly simple construction is obtained if the inlet openings are formed between a cross bar, which connects opposite parts of the lateral boundary of the liquid streams, and the lateral boundary. If the side wall is rotationally symmetrical about an axis and the cross bar is cuboid, the cross sections of the inlet openings will be shaped like circular segments. According to the invention such inlet openings may be combined with an outlet slot whose longitudinal direction is substantially parallel to the chords of the circular segments.

The droplet dispersion in the spray jet may be influenced by defined widenings of the cross section of the outlet opening in the direction of propagation of the spray jet. One embodiment of the spray nozzle according to the invention has an outlet slot whose cross-sectional area is widened at the narrow ends in the direction of propagation of the spray jet. A particularly large fan-out of the spray jet in the longitudinal direction of the outlet slot is achieved by this means.

In another embodiment of the spray nozzle the cross section of the outlet slot is widened in the centre of the long sides of the outlet slot in the direction of propagation of the spray jet. This measure enables the proportion of droplets propagating in the direction of the mean direction of propagation to be increased.

In another embodiment of the spray nozzle according to the invention the outlet opening and the mixing chamber have a common plane of symmetry, and guide walls are provided to bound the spray jet emerging from the outlet opening.

In another embodiment of the spray nozzle according to the invention the spray nozzles are asymmetrical in that the inlet openings have different cross-sectional areas and/or the guide walls are disposed on opposite sides of the outlet opening at a different distance from the latter. These two constructional measures result on the inlet and/or outlet side in an asymmetry of the spray nozzle which has an effect on the droplet dispersion in the spray jet—even if the mixing chamber is otherwise symmetrical. If this asymmetry is suitably prominent in quantitative terms, it is possible, in comparison with a symmetrical nozzle, to move the centroid of the droplet dispersion by a predetermined distance, influence the homogeneity of the droplet dispersion and vary the shape of the area for spraying. It is possible, inter alia, to form areas for spraying with more or less curved circumferential lines—instead of a rectangular area for spraying. A spray nozzle whose mixing chamber comprises a plane of symmetry will produce a particularly homogeneous droplet dispersion on a rectangular area for spraying with a centroid which is offset with respect to the plane of symmetry if the nozzle is formed asymmetrically on the inlet and the outlet side such that the inlet opening with the smaller cross-sectional area is disposed on the same side of the plane of symmetry as the guide wall which is disposed at the greater distance from the plane of symmetry. To achieve optimum results, the distances of the guide walls from the plane of symmetry may be adapted to the asymmetry of the nozzle on the inlet side, which is characterised, for example, by the difference in size of the cross-sectional areas of the inlet openings.

A spray nozzle according to the invention which is provided with a suitable outlet slot enables, for example, a rectangular area of a width of 10 cm and a length of 50 cm to be uniformly sprayed from a distance of approximately 45 cm. Spray nozzles of this kind may advantageously be used in a secondary cooling section of a continuous casting plant to cool strands of billet or bloom format, in which case one of the spray nozzles would replace 4–6 conventional full cone nozzles and in addition make a more uniform coolant application possible. The nozzle according to the invention may be constructed with an outlet slot of a length exceeding 10 mm and a width exceeding 5 mm. Openings of this size entail little risk of the outlet slot of the spray nozzle according to the invention becoming clogged due to soiling during operation, which is quite the opposite of conventional spray nozzles. The same applies to the inlet openings, which may be approximately of the same size as the outlet openings.

The asymmetrical embodiments of the spray nozzle according to the invention are used in various ways in a continuous casting plant. In a curved mould continuous casting plant, for example, portions of a curved strand with a rectangular cross section are cooled on the different sides in the region of the secondary cooling zone by superimposing areas for spraying in the form of rectangles and segments of circular rings. Such areas can be generated with the spray nozzle according to the invention by appropriately dimensioning the components thereof. Moreover, it is usual, when casting parts in succession, to vary the cross section of the strands to be produced. This results in the problem that, after changing the cross section in a longitudinal portion of a strand path, it is not just the size of an area for spraying which has to be adapted to the changed strand geometry, but also frequently the centroid of this area. When using conventional spray nozzles, these must all be replaced by other nozzles with a different area for spraying when the cross section is changed, in which case the position of the spray nozzles must also be appropriately adapted. The same object can be achieved by means of the spray nozzle according to the invention by positioning the spray nozzles at a predetermined point and optionally using spray nozzles with differing asymmetry which take account of the change in the centroids of the areas for spraying. This procedure eliminates the complex step of re-adjusting the spray nozzle each time the cross section is changed.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the spray nozzle according to the invention are illustrated in the following on the basis of diagrammatic figures, in which:

FIG. 1A is a longitudinal section through a spray nozzle;

FIG. 1B is a longitudinal section through the spray nozzle in FIG. 1A along the line B—B;

FIG. 2A is a cross section through the spray nozzle in FIG. 1A along the line A—A;

FIG. 2B is a plan view onto the spray nozzle in FIG. 1A along the arrow C in FIG. 1B and

FIG. 2C corresponds to FIG. 2B, although shows a different example;

FIG. 3A corresponds to FIG. 2A, although has inlet openings of a different size;

FIG. 3B corresponds to FIG. 2B, although has guide surfaces on the outlet side which are at a different distance from the outlet opening;

FIG. 3C corresponds to FIG. 1A, although is modified according to FIGS. 3A and 3B.

The two spray nozzles represented in FIGS. 1A–B and 2A–C are intended for spraying a rectangular area with liquid droplets.

DETAILED DESCRIPTION OF THE INVENTION

The spray nozzle **5** represented in FIGS. 1A–B and 2A–B is symmetrical with respect to a plane **35**. The spray nozzle **5** comprises a nozzle body **4** which has a cavity composed of a cylindrical portion **16** and a conical portion **17**. The cylindrical part has an opening **6** through which a liquid to be atomised can be admitted at a certain pressure p and is rotationally symmetrical with respect to a longitudinal axis **38**. The conical portion **17** tapers in the direction of the longitudinal axis **38** according to an opening angle a and has an outlet slot **30** for a spray jet **40** at the cone apex. The outlet slot **30** is symmetrical with respect to the plane of symmetry **35**, the longitudinal direction of the cross-sectional area of the outlet slot **30** lying in the plane of symmetry **35**.

As can be seen from FIGS. **2A** and 1A–B, a cross bar **8** in the cylindrical portion **16** separates a mixing chamber **15** consisting of a part of the cylindrical portion **16** and the conical portion **17** and leaves two inlet openings **9** and **10** free in the wall of the cylindrical portion **16**. The cross-sectional areas of the inlet openings **9** and **10** have the shape of a circular segment and lie symmetrically on different sides of the plane of symmetry **35**. The cross-sectional areas of the inlet openings **9** and **10** are of elongate shape, the directions of their longitudinal extent or the chords of the circular segments being parallel to the plane of symmetry **35**.

During operation a liquid to be atomised is delivered to the spray nozzle **5** along flow lines **7** at a pressure p through the opening **6** and routed into the mixing chamber **15** through the inlet openings **9** and **10**, forming a first liquid stream **12** and a second liquid stream **13**. Given an appropriate choice of opening angle α of the conical portion **17**, of the diameter D and the length L of the part of the cylindrical portion **16** which bounds the mixing chamber **15** (Figure 1B), the two liquid streams **12** and **13** are guided along the walls of the cylindrical portion **16** or conical portion **17** so as to meet at the outlet opening **30** and then form the spray jet **40**.

In FIG. 1B Φ_L denotes the angle which the fan-out of the spray jet describes in the plane of symmetry, i.e. characterises the angular range over which droplets leaving the outlet opening **30** are dispersed in the plane of symmetry **35**. Similarly Φ in FIG. 1A denotes the angular range over which droplets are dispersed perpendicularly to the plane of symmetry **35**. As indicated in FIGS. 1A and 1B, the angle Φ_L is substantially greater than Φ in the case of the spray nozzle **5** according to the invention. In order to enable as many droplets as possible to pass through the outlet slot **30** at the narrow ends of the outlet slot **30**, there is a widening **31** of the cross-sectional area of the outlet slot **30** in the direction of propagation **39** of the spray jet **40** at the narrow ends of the outlet slot **30**.

FIG. 2C indicates an alternative configuration of the outlet slot **30**. The cross section of the outlet slot **30** in FIG. 2C has widenings **32** in the direction of propagation **39** of the spray jet **40** in the centre of the long sides. The widenings cause the droplets to accumulate within the plane of symmetry **35** in the direction of the longitudinal axis **38**.

Guide walls **45**, **46** are disposed substantially parallel to the plane of symmetry **35**. Depending on the distance from the plane of symmetry **35**, the guide walls act as a boundary for the spray jet **40** emerging from the outlet opening **30** and/or to protect the spray jet **40** from external disturbances, e.g. movements of the ambient air.

The opening angle α=90° was selected in the example in FIGS. 1A and 1B. α=90° is a preferred value with regard to the homogeneity of the droplet dispersion in the spray jet **40**, the width of the fan-out of the spray jet **40** and the efficiency of the droplet production. However the spray nozzle according to the invention is also operational for 60°<α<130°, with 80°<α<100° being a preferred range.

The spray nozzle according to the invention as shown in FIG. 1A or 1B enables, for example, a rectangular area with dimensions of 120 mm×500 mm to be uniformly sprayed at a distance of 450 mm from the outlet opening. The angular distribution of the droplet paths is then characterised by Φ_L=58° and Φ=16°. Homogeneous droplet dispersions for a certain size of the mixing chamber **15** and a certain cross-sectional area of the inlet openings **9**, **10** are obtained for this spray range—depending on the size of the outlet slot **30**. For example, an outlet slot **30** of length 1=13.8 mm and width b=7 mm will produce a homogeneous droplet dispersion for a mixing chamber **15** of D=26 mm and L=11 mm. The optimum ratio of the sum of the two cross-sectional areas of the inlet openings **9**, **10** to the cross-sectional area of the outlet opening **30** at the same time has a value of 1.7 ±0.1. On account of the highly efficient production of droplets, the spray jet **40** produces a high impact pressure of 30 kg/m^2 on a sprayed surface from a distance of 450 mm at a pressure p=9 bar at the entrance **6** of the spray nozzle. The operating pressure p is between 1 bar and at least 10 bar.

If the cross-sectional area of the outlet slot **30** is smaller or greater, L and D must be reduced or increased accordingly. In this respect the optimum ratio of the sum of the cross-sectional areas of the inlet opening to the cross-sectional area of the outlet opening is between 1.5 and 2, preferably between 1.6 and 1.8, and the optimum ratio of the diameter D of the cylindrical segment **16** to the length L of the cylindrical segment **16** in the mixing chamber **15** is between 2 and 3. The impact pressure at the same reference distance becomes correspondingly lower or higher.

FIGS. 3A–C represent an asymmetrical spray nozzle **50**, which may be considered as a modification of the **25** previously-described spray nozzle **5** distinguished by the plane of symmetry **35**. The asymmetrical spray nozzle **50** differs from the symmetrical spray nozzle **5** in that the cross bar **8** is offset with respect to the plane of symmetry **35**, the inlet openings **9** and **10** consequently form circular segments with different areas A_1 and A_2 and the guide surfaces **45** and **46** are at different distances t_1 and t_2 from the centre of the outlet opening **30**. Where the asymmetrical spray nozzle **50** is concerned, A_1<A_2 and t_1, >t_2, i.e. of the inlet openings **9** and **10**, the one with the smaller cross-sectional area is disposed on the same side of the plane of symmetry **35** as the guide wall of the two guide walls **45** and **46** which is furthest away from the plane of symmetry **35**. Because of the different shaping or dimensioning of the inlet openings **9** and **10**, the liquid streams **12** and **13** transport different quantities of liquid (indicated in FIG. 3C by arrows with a line thickness corresponding to the quantity of liquid). As the liquid streams **12** and **13** are not symmetrical with respect to the lane of symmetry **35** in this configuration and droplets with an asymmetrical momentum distribution are consequently produced when the liquid streams meet, depending on the distance x from the plane of symmetry **35**, the spray jet **40** is characterised by a droplet dispersion P(x) whose maximum is located at a distance x_M from the plane of symmetry **35** on the side opposite the inlet opening **10**. The distance x_M may be varied by a suitable presetting of the widths w_1 and w_2 of the inlet openings **9** and **10**. A rectangular spraying area with a homogeneous droplet distribution P(x) in a plane perpendicular to the plane of symmetry **35** will result if the distances t_1 and t_2 of the guide

walls **45** and **46** are appropriately adapted. If the distances t_1 and t_2 are not optimally adapted to w_1 and w_2, this may result in a spraying area which is not rectangular, instead having the shape of a segment of a circular ring, for example.

What is claimed is:

1. A spray nozzle for spraying a continuous casting product with a cooling liquid, including a mixing chamber; a first inlet opening and a second inlet opening for injecting the liquid into the mixing chamber thereby forming a first liquid stream and a second liquid stream in the mixing chamber; an outlet slot, disposed downstream, for a spray jet, wherein at least one mixing chamber wall is formed as a guide surface for the liquid streams and is shaped at the outlet slot such that the liquid streams meet at an angle, which is between 60° to and 130°, at the outlet slot and then forms the spray jet;

   wherein the mixing chamber has a taper at the outlet slot with an opening angle at the outlet slot of between 60° and 130°, and the taper forms a part of the guide surface, and the outlet slot and the mixing chamber have a common plane of symmetry.

2. A spray nozzle according to claim **1**, wherein the mixing chamber has a cylindrical segment between the taper and the inlet openings.

3. A spray nozzle according to claim **2**, wherein the ratio of the diameter of the cylindrical segment to the length of the cylindrical segment is between 2 and 3.

4. A spray nozzle according to claim **1**, wherein the inlet opening in each case have a cross-sectional area of elongate shape and the directions of their longitudinal extent are in each case substantially parallel to the direction of the longitudinal extent of the outlet slot.

5. A spray nozzle according to claim **1**, wherein the mixing chamber has a side wall which bounds the liquid streams at the side, and the inlet openings each opens into the mixing chamber.

6. A spray nozzle according to claim **5**, wherein the inlet openings are formed between the side wall and a cross bar.

7. A spray nozzle according to claim **1**, wherein the ratio of the sum of the two cross-sectional areas of the inlet openings to the cross-sectional area of the outlet slot is between 1.5 and 2.

8. A spray nozzle according to claim **1**, wherein the longitudinal direction of the outlet slot lies in a plane of symmetry, and the inlet openings are disposed on different sides of the plane of symmetry.

9. A spray nozzle according to claim **1**, wherein the cross section of the inlet openings is shaped like a circular segment.

10. A spray nozzle according to claim **1**, wherein the cross-sectional, area of the outlet slot has a widening at the narrow ends in the direction of propagation of the spray jet.

11. A spray nozzle according to claim **1**, wherein the cross section of the outlet slot has a widening in the center of the long sides of the outlet slot in the direction of propagation of the spray jet.

12. A spray nozzle according to claim **1**, wherein guide walls are disposed in the direction of the longitudinal extent of the outlet slot to bound the spray jet emerging from the outlet slot.

13. A spray nozzle according to claim **12**, wherein the guide walls are disposed on opposite sides of the outlet slot at different distances from the outlet slot.

14. A spray nozzle according to claim **13**, wherein the inlet openings have different cross-sectional areas, the inlet opening with the smaller cross-sectional area is disposed on the same side of the plane of symmetry as the guide wall which is disposed at the greater distance from the plane of symmetry.

15. A spray nozzle according to claim **1**, wherein the inlet openings have different cross-sectional areas.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,360,973 B1
DATED : March 26, 2002
INVENTOR(S) : Adrian Stilli

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [30], **Foreign Application Priority Data,** delete "Nov. 14, 1997 (CH)..............2639/97" and add -- Nov. 14, 1997 (CH)...................26391/97 --.

Signed and Sealed this

Fifteenth Day of October, 2002

Attest:

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

Attesting Officer

United States Patent [19]

McDonnell et al.

[11] 3,864,692

[45] Feb. 4, 1975

[54] TIME DEPENDENT DEFLECTION CONTROL FOR INK JET PRINTER

[75] Inventors: James A. McDonnell, Binghamton; Robert E. McGuire; Raymond Radlinsky, both of Endwell, all of N.Y.

[73] Assignee: International Business Machine Corporation, Armonk, N.Y.

[22] Filed: Sept. 26, 1973

[21] Appl. No.: 401,006

[52] U.S. Cl. 346/75
[51] Int. Cl. G01d 15/18
[58] Field of Search 346/75, 140

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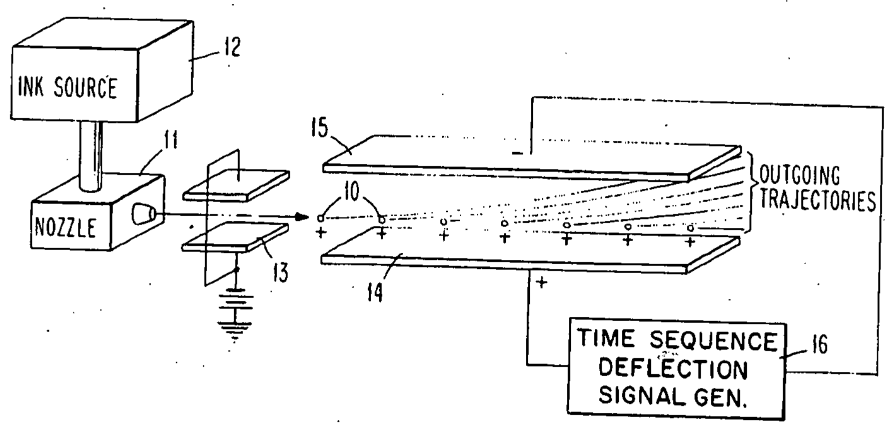
Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—K. P. Johnson

[57] ABSTRACT

An ink jet printer in which ink droplets issuing from a source serially pass through an electrically energizable deflection field which is activated at regularly recurring intervals. Deflection of the drops occurs along different trajectories toward a recording medium because of the variable time each droplet is subjected to the energized deflection field. The droplets which are deflected have the same physical or electrical characteristics and are not given differing charges, for example, before entry into the deflection field. Both electrically chargeable droplets and magnetic droplets may be used as the marking fluid when directed according to time dependent deflection. Generally, the deflection field is of sufficient length to include simultaneously all droplets which will comprise a full character stroke on the recording medium and the deflection signal is a square wave selectively applied. However, deflection fields may be shortened and the applied signal may either increase or decrease with time during the energizing interval. In addition, apparatus may be included to produce deflection along either of two coordinate axes and means are disclosed to select droplets required for printing while discarding others during issuance of the droplets from the source at a fixed generation rate.

15 Claims, 10 Drawing Figures



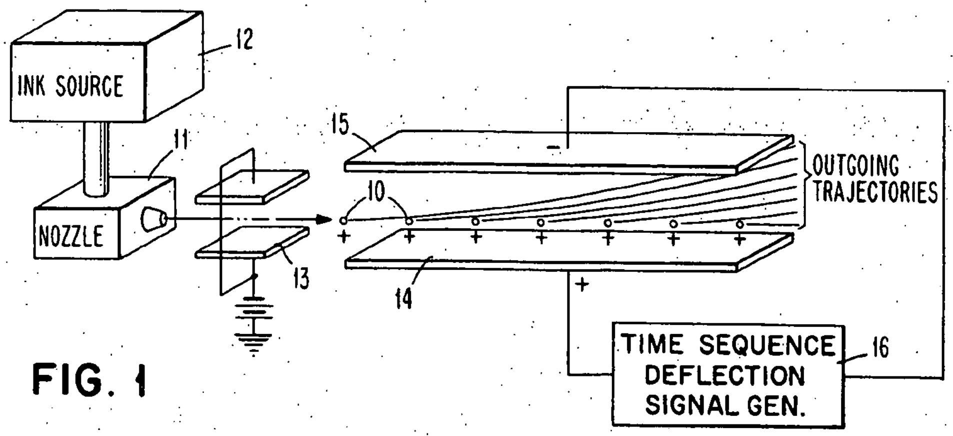


FIG. 1

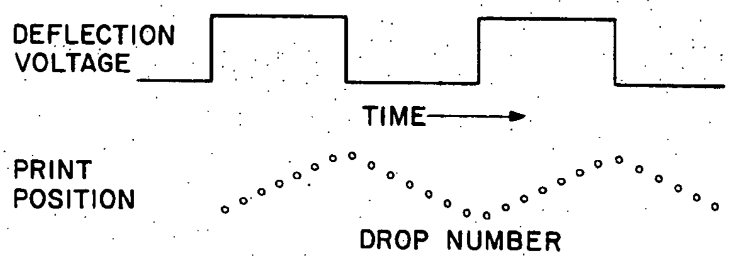


FIG. 2

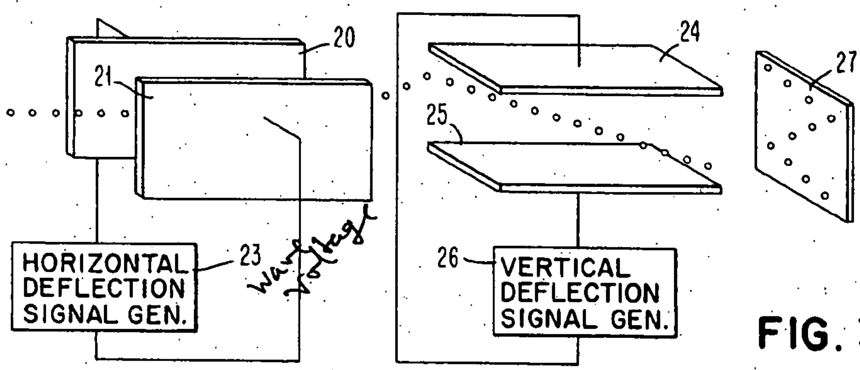


FIG. 3

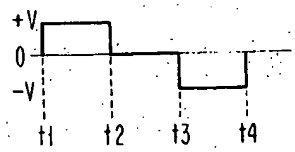


FIG. 4a

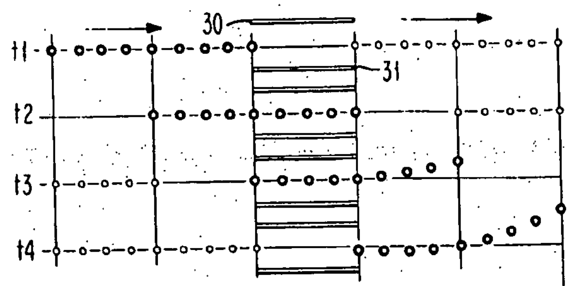


FIG. 4b

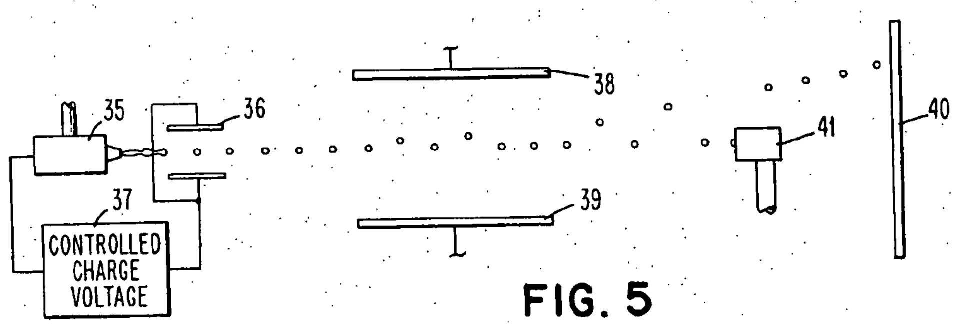


FIG. 5

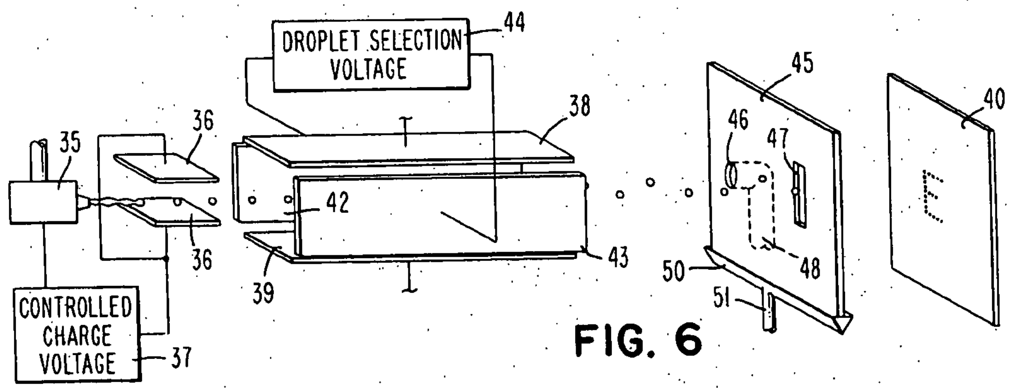


FIG. 6

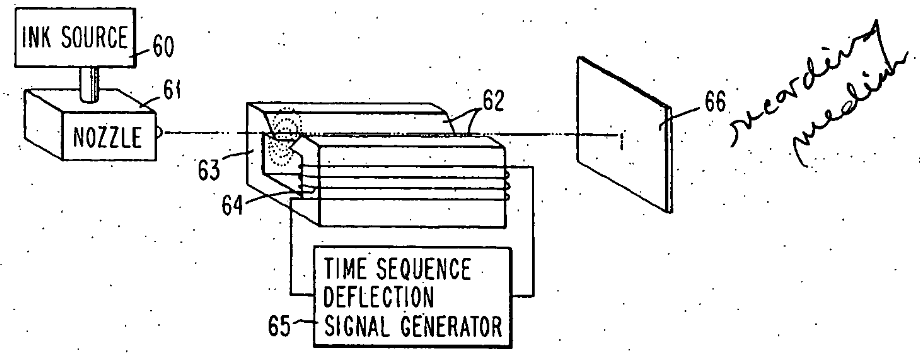


FIG. 7

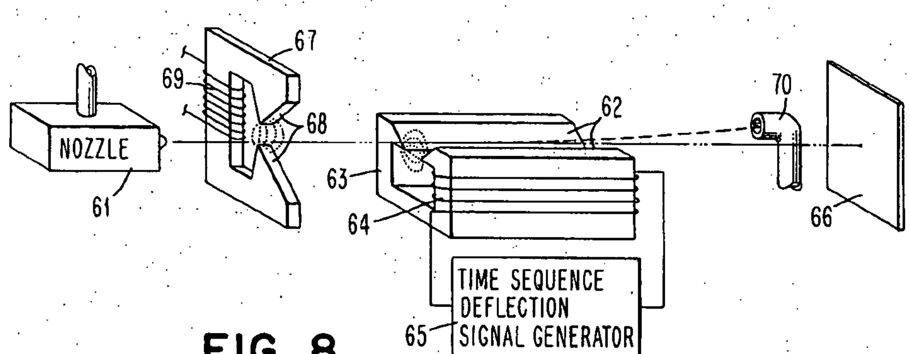


FIG. 8

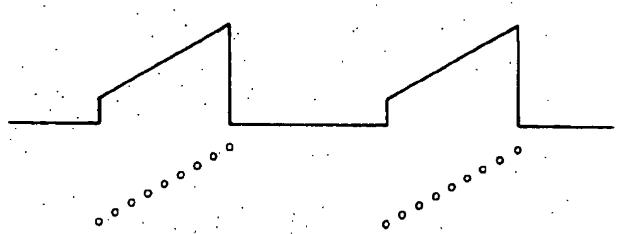


FIG. 9

TIME DEPENDENT DEFLECTION CONTROL FOR INK JET PRINTER

BACKGROUND OF THE INVENTION

The present invention relates to graphic display recorders and more particularly to ink jet printers employing selectively directed droplets for forming characters and the like on a recording medium.

Ink jet printers are well known. Examples of such printers are disclosed in U.S. Pat. No. 2,600,129, issued June 10, 1952 to C. H. Richards; U.S. Pat. No. 3,596,275, issued July 27, 1971 to R. G. Sweet; U.S. Pat. No. 3,500,436, issued Mar. 10, 1970 to R. W. Nordin; and U.S. Pat. No. 3,510,878, issued May 5, 1970 to C. E. Johnson, Jr.

Character printing with a stream of ink droplets is generally accomplished electrostatically in the prior art by selectively deflecting the stream repeatedly along one direction while the recording medium on which the ink is deposited moves at a slower velocity along a second orthogonal direction. This results in a matrix type of printing in which droplets not required are directed to a gutter or else not produced. Each desired droplet is given an electrical charge at the time of formation that corresponds with its assigned position along the line of deflection and directed through an electrostatic field of constant strength. The several droplets are there deflected in proportion to their respective charges.

This type of printing requires sophisticated electrical circuitry. The charges for each desired droplet must be accurately established and maintained through the duration of printing in order to provide uniformly spaced and accurately placed droplets on the record medium. Because of the aerodynamic effects and interdrop electrical characteristics, compensation circuits are usually required to maintain the uniform spacing of droplets. In addition, changes in ink temperature or viscosity affect the time of drop breakoff and hence the charge placed on the droplet; this is overcome by using synchronizing circuits which rely on further detection devices to maintain proper droplet charge.

When printing with magnetic ink droplets, it has been found that although no charging is required, the magnetic deflection field must be varied for each droplet in order to attain the proper droplet spacing. This, therefore, requires a series of magnetic deflection elements between the droplet formation point and recording medium for the selective application of various and suitable deflection energies. This is done by either providing a single magnetic field and varying the flux density or by providing a succession of magnetic fields which can be selectively energized as each droplet progresses toward the record surface. As with the electrostatic printing, such control circuits become complex, expensive and are usually difficult to maintain at the proper stability.

It is accordingly a primary object of this invention to provide improved ink droplet printing apparatus for producing graphic displays such as alphanumeric characters.

Another important object of this invention is to provide ink droplet printing apparatus in which droplet deflection is accomplished by energizing the deflection field at selected predetermined times and the droplets, having uniform charges or latent magnetization, are given trajectories toward a recording medium according to their time in the field.

Another object of this invention is to provide ink droplet printing apparatus in which the ink droplets used for printing are equally charged and the deflection field is electrically or magnetically energized for regular intervals of time to establish different droplet trajectories.

Another object of this invention is to provide ink droplet printing apparatus in which the droplets are selectively charged at either of two levels and may optionally be synchronously charged with droplet production or asynchronously charged.

A still further object of this invention is to provide ink droplet printing apparatus in which droplets are given deflection trajectories according to the time that is spent in either an electrostatic deflection field or a magnetic deflection field.

Another object of this invention is to provide ink droplet printing apparatus having a pair of selectively energizable deflection fields between a droplet source and recording medium in which droplets are given deflection in proportion to the time spent in either of said fields.

SUMMARY OF THE INVENTION

The foregoing objects are attained in accordance with the invention by serially producing a stream of like-charged ink droplets, directing them through a selectively energizable deflection field toward a recording medium, and selectively energizing the field in accordance with the position of the droplets therein so as to cause said droplets to assume a trajectory dependent upon the time each droplet is subjected to the field. In a simple case, the field is merely turned on and then off when the series of droplets is between the plates. Thereby, each successive droplet later in the series is subjected to the field for a longer period and will have a greater deflection from its initial path of travel. The droplets are preferably produced in sufficient number to record a full line of the recording matrix if every droplet is present. When using charged droplets in an electrostatic field, each of the droplets to be used in the series is given a like charge and droplets to be discarded are given a different or no charge. Charging pulses may be provided for a predetermined time until the selected series is fully charged or may be synchronously applied by energizing the droplets as each is produced. The ink drop printing apparatus of the invention can also be used with magnetic ink droplets. Of course, in this case no charge is placed on the droplets but they are likewise produced in a sufficient number in a series to complete one line of the matrix in the case where a full line is required. Unwanted magnetic droplets may be deflected by an auxillary device from the character forming deflection field. The deflection field is preferably energized for regularly recurring time intervals and the magnitude of the energizing signal may be constant or in some cases varied.

Because of the simplified deflection control means much of the expense necessitated by the circuits for the electrostatic control means heretofore known has been eliminated. Ink droplet charging can be done in a binary fashion either synchronously or asynchronously and the deflection field energization may be accomplished on a regularly recurring time cycle even though relatively complex characters have to be formed. The

invention has the advantage of not being restricted to field energization signals of constant amplitude but other signals such as ramp or step signals may be applied if desired to produce the necessary deflection trajectories for the droplets. The deflection technique is suitable for use with either electrostatic deflection fields or with magnetic deflection fields and carries with it the above named advantages in either case.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates an ink drop deflection apparatus constructed in accordance with the principles of the invention.

FIG. 2 is a timing diagram showing relationship between a signal applied to a deflection field and the impact positions of ink droplets responding thereto.

FIG. 3 is a modification of the apparatus shown in FIG. 1 in which a second selectively energizable deflection field has been added to enable two dimensional deflection.

FIGS. 4*a* and 4*b* illustrate another waveform that may be applied to the deflection field and the relationship of the droplet trajectories in accordance therewith.

FIG. 5 is a diagram of an ink droplet printing apparatus in which a gutter is used to receive all unwanted ink droplets.

FIG. 6 illustrates an aperture plate in conjunction with the apparatus of FIG. 3 in which improperly charged droplets and unwanted droplets can be eliminated.

FIG. 7 is a schematic diagram of ink droplet printing apparatus for magnetic ink which incorporates the principles of the invention.

FIG. 8 is a schematic diagram of magnetic ink droplet deflection apparatus in which unwanted droplets can be eliminated.

FIG. 9 is a timing diagram showing both a time and amplitude variable energization signal for a magnetic deflection field and showing the relative trajectories of ink droplets deflected by the field so energized.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIG. 1 a stream of ink droplets 10 issues from a nozzle 11 which is supplied with ink under pressure from source 12. The nozzle and ink source, which may be of types well known in the art, produce a stream of ink in the order of 0.001 inches in diameter which breaks up into individual droplets in the vicinity of the charging electrode 13. As each droplet breaks from the filament of ink issuing from the nozzle, it carries with it an electric charge. In the diagram shown, each droplet receives the same charge and the droplets pass serially between a pair of deflection electrodes 14 and 15 which are each connected to opposite polarities of a time sequence deflection signal generator 16. The generator periodically energizes plates 14, 15 to create a transverse electrostatic field of the polarity indicated. At the moment, it may be assumed that generator 16 produces square wave pulses which vary between zero and a positive value. The system is synchronized such that the deflection plates are initially uncharged and the droplets are produced in series in a group. When the first droplet of the group reaches the end of deflection plates 14 and 15, to the right, and is about to emerge therefrom, the last droplet of the group has just entered between the plates. At this time, an electric field at a fixed value is established between plates 14 and 15 from signal generator 16 and will remain until the last droplet in the series reaches the right hand edge of the plates.

When this occurs, each of the equally charged droplets in the group will be influenced by the electric field between plates 14 and 15 for a different amount of time. The first droplet of the group which is about to emerge from the plates will experience electric field for the shortest amount of time and the last droplet of the group, which has just entered between the plates, will experience the field for the greatest amount of time as it travels the entire length of the deflection plates. Intermediate drops of the groups will be influenced by the electric field for differing time periods and will acquire a transverse velocity component proportional to the time-integral of the field they experience. Since they have a substantially constant velocity, this is, in turn, proportional to the distance integral of the field, from the position of the droplet at the instant the field is turned on to the end of the field region or termination of the field. The first droplet will experience little or no deflection as it leaves the field region at the time the field is set up, whereas the last drop is fully deflected since it travels the full length of the field region under the influence of the field. The uniformly spaced intermediate drops acquire equal increments of transverse velocity because of the electric field distribution along the length of the deflection plates 14 and 15 is uniform. After traveling along the trajectories toward the recording surface, not shown, the deflection droplets are arranged to produce a line scan which is approximately linear. The deflection plates can be of a length to allow sufficient droplets therebetween to comprise a character stroke or one line of a matrix arrangement of droplets.

If the incoming stream of droplets is continuous and uniformly spaced, a new group is located in position between deflection plates 14 and 15 at approximately the time the last drop of the first group of droplets has left the deflection plate region. This second group of droplets is given a line scan deflection because the deflection field is now reduced to zero because of the termination of the square wave signal from generator 16. The difference with the second group of droplets is that the last droplet in that group receives little or no deflection because the electric field between the deflection plates is turned off at approximately the time it enters the region between the plates. The foremost drop of the group is fully deflected because electric field was on during nearly the whole of its transit time. Likewise, the intermediate droplets are deflected proportional amounts. Thus, the scan direction reverses for the second group of droplets.

If a third group of droplets follows normally spaced behind the second group, it enters the region between deflection plates 14 and 15 when the electric field is zero and is scanned when the field is switched on again by the next positive square wave pulse from generator 16. The result is a scan moving back and forth in a vertical direction. Naturally the scan can be made to travel back and forth in a horizontal direction if the deflection plates are rotated 90 degrees about the nominal droplet path.

FIG. 2 illustrates the relationship between the deflection of the groups of droplets discussed above and the

square wave voltage signal applied to deflection plates **14** and **15** of FIG. **1.** It will be seen that the droplets are proportionately deflected in one direction when the square wave pulse is present to establish a transverse deflection field, and the droplets are deflected in the opposite direction when the deflection voltage returns to zero.

In FIG. **1** a scheme is shown for deflecting the ink droplets back and forth in one dimension, that is, the vertical direction. Since all the droplets have the same charge, it is possible, if required, to provide another scan direction by passing the droplets between a second pair of deflection plates, positioned, for example, orthogonal to the first pair of deflection plates. With this technique, a matrix scan can be created without moving the recording surface. Referring to FIG. 3, a system having two pairs of deflection plates is shown. A stream of equally charged ink droplets is produced using a structure described for FIG. **1.** The stream of droplets is directed between the first pair of deflection plates **20–21** which are connected to a source of square wave voltage **23** similar to signal source **16** of FIG. **1.** The droplets are deflected back and forth in a one dimensional scan as described in relation to FIG. **1,** except that the direction of scan is horizontal due to the position of deflection plates **20** and **21.** The deflected droplets emerging from plates **20** and **21** pass between a second pair of deflection plates **24** and **25** where they are deflected in the second direction such as vertical to produce a second scan that is relatively slow. Because of the relative slowness of the scan, the droplet transit time is not critical and the scan can be established by a field produced by a ramp voltage from a deflection signal generator **26** connected to plates **24** and **25,** just as with the conventional cathode ray tube deflection signal. Transit time of the droplets through deflection plates **24** and **25** may have the effect of delaying the deflection and distorting it for a period equal to the transit time near the leading and trailing edges of those plates. These effects can be nullified by initiating the ramp voltage before the first active droplet of the complete raster scan enters the electric field region between the second set of deflection plates **24** and **25** and ending only after the last active droplet has emerged.

The deflection voltage from signal generator **26** need not be a ramp voltage; a staircase deflection voltage signal such as applied to deflection plates **20** and **21** may also be employed provided that deflection plates **24** and **25** are long enough to encompass all the droplets in the raster. Whether a ramp deflection voltage signal or a staircase voltage signal is used, a zig-zag raster is obtained as illustrated on recording medium **27.**

The invention has been described assuming that the signal generator produces regularly spaced square waves and that the charged ink droplets are produced continuously. The result was a zig-zag raster scan on the recording medium. If the droplets are produced in groups of a length sufficient to produce one line of a matrix, with a gap created between droplet groups, it will be obvious that parallel lines having a single sweep direction can be produced. With this in mind, another modification of droplet control is shown in FIGS. **4***a* and **4***b*.

IN FIGS. **4***a* and **4***b*, there is shown a technique of extending the line length in a matrix wherein the deflection electrodes are half the length of a series of droplets which are to make up the matrix line of print. This is accomplished by square wave signals which occur alternately, positively and negatively with respect to a zero potential line as indicated in FIG. **4***a*. The time in this example is divided into equal increments with the beginning and ending of the increments designated *t***1,** *t***2,** *t***3,** *t***4.** In FIG. **4***b*, a pair of deflection plates **30** and **31** are shown, between which successive groups of serially arranged ink droplets are directed toward a recording medium not shown. Considering the group of droplets denoted by heavy lines, at time *t***1,** a positive square wave is applied to deflection plates **30** and **31** for the time *t***1** and *t***2.** As seen in FIG. **4***b*, the first droplet of the series of charge droplets is about to enter the deflection field and will be subjected to the transverse force of the field during its entire traversal from the beginning of the deflection plates to the end of the deflection plates. The succeeding three drops will experience the deflection force, each for a slightly less interval of time and the fifth drop in the series will just start to enter the deflection field at time *t***2** when the square wave signal is terminated. Each of the first four droplets will have received varying transverse velocity components during the passage through the field and during the time required for the fifth droplet to travel to the end of the deflection field, which is not energized, no transverse forces will be experienced by the last five droplets. However, at time *t***3,** a negative square wave is applied to the deflection electrodes and as the last four droplets continue in such a field, they will receive transverse velocity components in the direction opposite to the first four. It will be noted that the center droplet of the series does not experience any deflection force, since the deflection field was terminated as it entered the plates **30, 31** and the field was energized just as that droplet left the deflection plates. With this technique, a longer matrix can be generated at the recording surface.

The description thus far has indicated that a series of droplets generated should be formed in groups to coincide with the regularly recurring deflection field energization. FIG. **5** illustrates how ink droplets can be formed continuously and then selectively eliminated to form groups or to form voids within a group which may be required for the matrix line of a character being formed. Droplets issue continuously from nozzle **35** and pass between charging electrodes **36,** then between deflection electrodes **38** and **39** while proceeding toward recording medium **40.** However, charging electrodes **36** are intermittently controlled to place charges only on certain of the droplets issuing. The uncharged droplets, as they pass through the deflection field, cannot be deflected from their nominal path, and will be collected in a gutter **41** which, as is usual in the art, is connected by a vacuum pump to the ink supply for the nozzle for reuse. Those droplets that are charged will be deflected in accordance with the excitation voltage on deflection plates **38** and **39.** With the apparatus as shown, it is preferable to place a bias voltage on deflection plates **38** and **39** to deflect all charged droplets above gutter **41.** The applied control signal can then be superimposed upon the bias signal to achieve the desired droplet deflection.

It has been mentioned above that the charge voltage for droplets at the charging electrode may be asynchronously applied rather than synchronously. By this is meant that the charge voltage is not applied in timed relation with each droplet at breakoff from the filament

extending from the nozzle. As seen in FIG. 6, droplets issue from nozzle 35 and form droplets in the vicinity of charge electrodes 36 which are controlled by charge circuit 37. Charge circuit 37 will apply the binary (charge or no charge) signal for the time necessary to charge the droplets required within or for a matrix line on the recording medium. As both the charged and uncharged droplets proceed toward the recording medium 40, they pass between two pairs of orthogonally disposed deflection plates. One pair is selection electrodes 42 and 43 controlled by selection voltage circuit 44. This circuit is essentially a continuous bias voltage which has the effect of deflecting all charged droplets from the uncharged droplets. Simultaneously all droplets proceed between vertically disposed deflection electrodes 38 and 39 which operate with the time dependent on-off deflection signal as described earlier with regard to FIGS. 1–4. Interposed between recording medium 40 and the selection and deflection electrodes 42, 43 and 38, 39 is a mask or plate 45 which has a gutter opening 46 and a print opening 47. Opening 46 communicates with a duct 48 which returns to a sump, not shown. Mask 45 is fitted with a collection channel 50 at the bottom thereof which is connected to a duct 51 which likewise returns to the sump.

In the operation of the structure of FIG. 6, droplets issuing from nozzle 35 are either charged or not charged depending upon whether they are required for printing. Those desired are all charged to a common level, while those not required are given no charge. As the continuous series of droplets passes into the electric field established between electrodes 42, 43, those carrying a charge will be deflected toward opening 47 in mask 45. Droplets uncharged will continue to opening 46 in the mask and return through duct 48 to the sump for reuse. Since charging has occurred asynchronously some droplets may have received their charge during the time of transition from the zero voltage on plates 36 to full value or during the transition in the opposite direction and not be fully charged or uncharged. These droplets when passing between electrodes 42 and 43 will be only partially deflected toward opening 47 from opening 46 and will impact mask 45 between the two openings thereby draining into channel 50. When the fully charged droplets reach vertical deflection electrodes 38 and 39, the desired time deflection signal is applied or removed from those electrodes to produce the required vertical change in trajectory. These droplets will continue through opening 47 and impact recording medium 40. Deflection electrodes 38 and 39 are controlled as described with regard to FIG. 1.

The technique of time dependent deflection of ink droplets is also readily adaptable to printing with magnetic ink, as illustrated in FIG. 7. Magnetic ink is supplied from pressurized source 60 to nozzle 61 and issues therefrom as a stream, subsequently breaking into droplets. The droplets, however, are not charged as is the case with electrostatic deflection. The droplets are directed between the pole pieces 62 of an electromagnet 63 which is energized by winding 64 for selective periods of time to subject each of the droplets in the series to different durations of transverse forces as the droplets traverse the nominal flight path. Energization is done with an intermittently controlled signal generator 65. During their travel, the droplets enter the magnetic field of the electromagent 62 and experience a transverse force in the direction of the higher density flux paths. In other words, the transverse forces will be downward and deflection will occur in proportion to the time each droplet is subjected to the applied forces. As described with reference to FIG. 1, if successive series of droplets are formed and directed through the magnetic field, a signal such as a regularly applied square wave can be used to produce successive parallel lines on recording medium 66 if the recording medium is moved laterally of the stream.

Since it is more practical to generate magnetic ink droplets continuously, unwanted droplets must be eliminated. One technique for selective elimination is shown in FIG. 8. Droplets of magnetic ink are formed by nozzle 61 and directed as in FIG. 7 between pole pieces 62 of electromagnet 63 having winding 64. The winding is controlled by time sequence deflection signal generator 65. The ink droplets have a nominal path which will impact recording medium 66 at the desired print area. To this point the structure of FIG. 8 is similar to that of FIG. 7; however, in order to achieve the selectivity of ink droplets, horizontal selector magnet 67 is arranged so that its pole pieces 68 are on opposite sides above and below the droplet path. The selector magnet also has a control winding 69 thereon which is connected with a suitable signal source for intermittently applying energizing current to produce a magnetic flux field about the droplet path. The selector magnet 67 is a thin ferromagnetic material which is less than the drop-to-drop spacing so that when energized the selector magnet will operate only on a single drop. As droplets pass along their nominal path the selector magnet can be intermittently energized which will create a leftward deflection due to the flux gradient causing the selected drops to depart sufficiently from the desired drops to enter a gutter 70. Desired drops will continue to pass between the pole pieces 62 of the vertical deflection magnet 63 so that ink droplets are deflected according to the time subjected to the field of magnet 63. Droplets deflected from the nominal path by selector magnet 67 will also be vertically influenced by the electromagnet 63 but gutter 70 is made to have a sufficiently long vertical opening to catch such deflected droplets.

In certain instances, particularly deflection of magnetic ink, the amount of droplet deviation provided by an electromagnet may not be sufficient to produce the length of line scan desired. This may be due to the electromagnet characteristics or the lack of space between the nozzle and recording medium. A technique of extending the scan distance is to superimpose a ramp signal on the time sequence deflection signal which is applied to the vertical scan magnet. This, of course, applies a greater transverse force to the droplets during the time that they are within the activating magnetic field. The deflection signal may be longer than the traversal time required for a droplet through the magnetic field. It should also be noted that such a technique is equally applicable to electrostatic embodiment of FIG. 1. Although a ramp has been shown in FIG. 9, other wave forms may be employed to attain the desired droplet deflection.

There has been described improved ink jet printer structure which uses ink droplets having a binary type of charge, being either charged or uncharged and which permits the use of a simplified deflection circuit. The technique is also adaptable to magnetic ink jet printers.

While the invention has been particularly shown and described with reference to preferred embodiments, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A fluid drop control system comprising:
means for directing a series of drops of marking fluid of like deflection characteristics along a path;
selectively energizable means adjacent said path for establishing a deflection field simultaneously encompassing said drop series and having a force component transversely of said path acting to deflect said drops moving along said path; and
means for energizing said deflection means for a predetermined time to subject each drop in said series of drops to said transverse force for different times for unidirectional deflection and impart to each drop in said series a different trajectory from said path beyond said deflection means according to the time subjected to said force.

2. Apparatus as described in claim 1 wherein said energizing means is operable for regular intervals of time.

3. Apparatus as described in claim 1 wherein said deflection means is energizable by electrical signals.

4. Apparatus as described in claim 1 wherein said directing means produces drops in a series uniformly spaced from each other.

5. Apparatus as described in claim 1 wherein the energy supplied by said energizing means is of a constant level during said predetermined time.

6. Apparatus as described in claim 1 wherein said means for energizing said deflection means is also operable to vary the magnitude of energization during each predetermined time period.

7. A fluid droplet marking system comprising:
a recording medium:
means for directing droplets of marking fluid of like deflection characteristics of substantially uniform size serially along a path towards said recording medium;
selectively energizable deflection means between said directing means and said recording medium for establishing a force component encompassing a series of said droplets and acting transversely thereon as said droplets are moving along said path to deflect said droplets therefrom; and
means for uniformly energizing said deflection means for a predetermined time to simultaneously act on a plurality of said droplets to induce unidirectional deflection and to cause each said droplet in said series to be deflected according to the time subjected to said force and follow a different trajectory from said path toward said recording medium.

8. Apparatus as described in claim 7 comprising second selectively energizable deflection means between said directing means and said recording medium for establishing a force component transversely of said path and in a direction different from the force component of the first-mentioned deflection means to deflect said drops from said path; and
second means for energizing said second deflection means for a second predetermined time for altering the trajectory of selected ones of said droplets passing from the first deflection means toward said recording medium.

9. Apparatus as described in claim 8 wherein said deflection means and said second deflection means are arranged to act simultaneously on said droplets when energized.

10. Apparatus as described in claim 7 further including means for inhibiting certain selected droplets from said directing means from reaching said recording medium.

11. Apparatus as described in claim 7 wherein said deflection means is a pair of electrically energizable plates on opposite sides of said path and said energizing means produces an electrical field therebetween; and
further including charging means between said directing means and said deflection means for establishing a uniform electrical charge on selected ones of said droplets.

12. Apparatus as described in claim 11 wherein said charging means includes a source of binary voltage signal selectively operable for applying charging voltage only to selected ones of said droplets from said directing means, leaving others of said droplets in said series uncharged and not deflectable by said deflection means; and
interceptor means located between said directing means and said recording medium for intercepting and collecting said uncharged droplets.

13. Apparatus as described in claim 7 wherein said energizing means applies a square wave signal to said deflection means.

14. Apparatus as described in claim 7 wherein said energizing means includes means to establish a bias energy level on said deflection means.

15. A fluid drop control system comprising:
means for producing drops of marking fluid having like deflection characteristics in a force field and directing a series of said drops along a path;
selectively energizable means adjacent said path for establishing a deflection field simultaneously encompassing said drop series and having a force component transversely of said path acting to deflect said series of drops moving along said path; and
means for energizing said deflection means for a predetermined time to subject each drop in said series of drops to said transverse force for different times according to the position of each said drop in said series while moving past said selectively energizable means and impart to said drops unidirectional deflection and in different trajectories from said path beyond said deflection means.

* * * * *

United States Patent [19] | [11] **3,798,656**
Lowy et al. | [45] **Mar. 19, 1974**

[54] **INK RETURN SYSTEM FOR A MULTIJET INK JET PRINTER**

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[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[22] Filed: **July 28, 1972**

[21] Appl. No.: **275,990**

[52] **U.S. Cl.** **346/1**, 346/75, 346/140
[51] **Int. Cl.** **G01d 15/18**
[58] **Field of Search** 346/75, 140

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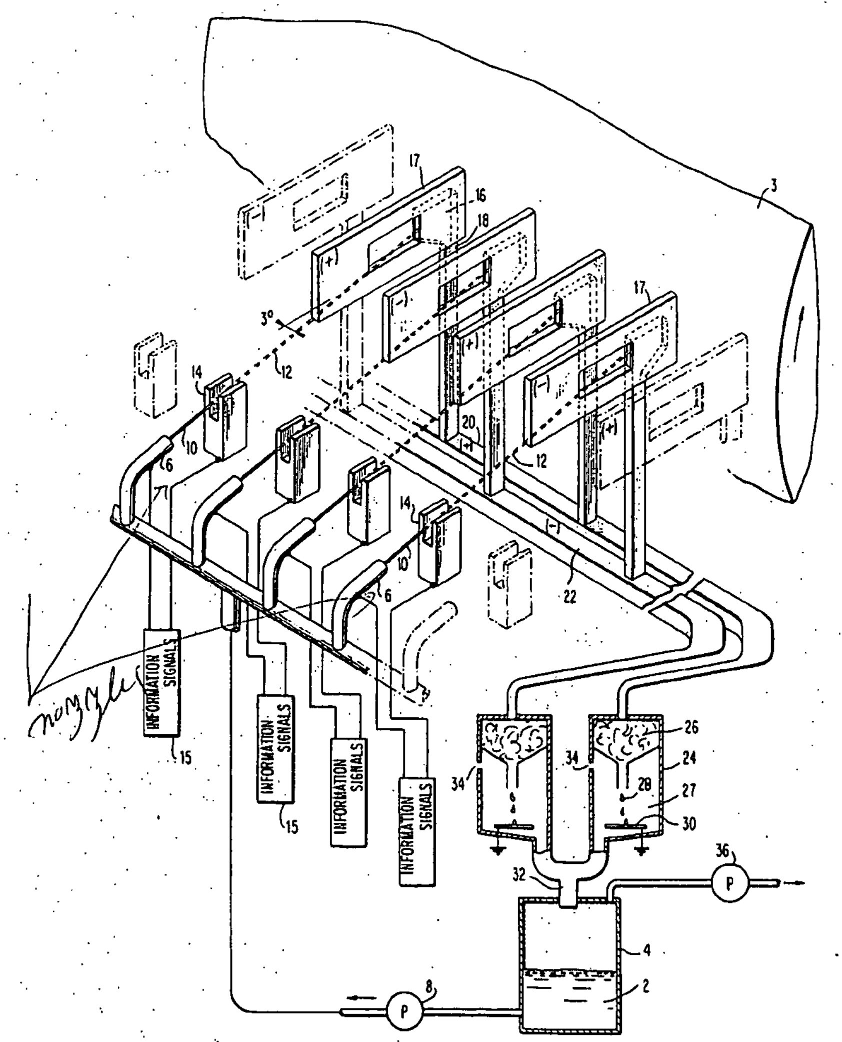
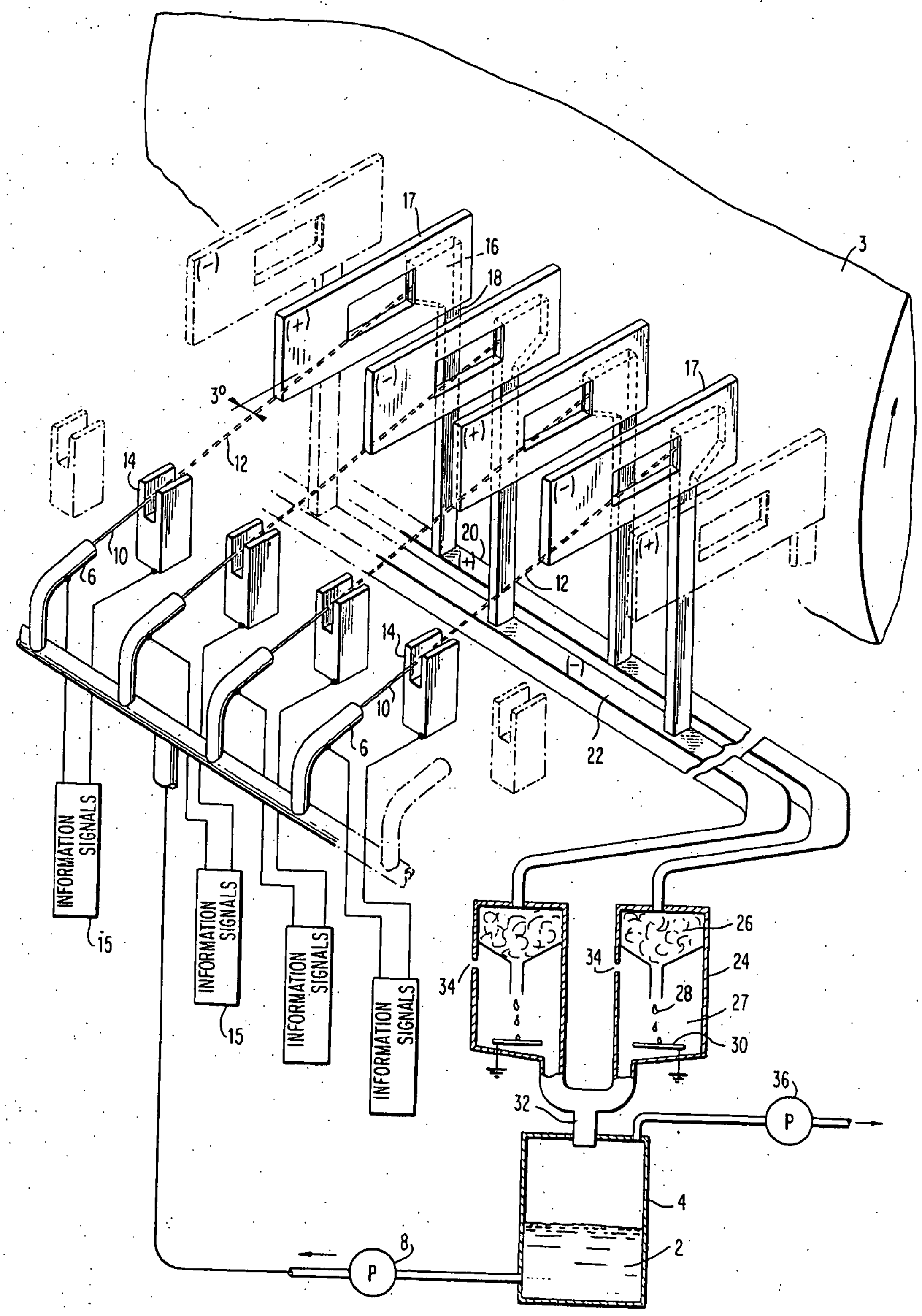
Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—Sughrue, Rothwell, Mion, Zinn & Macpeak

[57] **ABSTRACT**

A multi-jet, ink jet printer having deflection plates at a positive or negative potential with respect to ground which includes catch chambers for returning unused ink to an ink reservoir. Non-information bearing ink droplets are passed uncharged to a catch chamber and from there through a return conduit system to the ink reservoir. To help direct the ink droplets to the catch chambers, the catch chambers are mechanically biased toward the trajectory of the uncharged droplets by placing them at a slight angle with respect to the trajectory. To prevent short-circuiting of the deflection plates to ground potential, the return conduit system includes denebulization chambers which convert the returning ink stream into large drops thus developing a high resistance path between the deflection plates and the reservoir ink at ground potential.

10 Claims, 1 Drawing Figure

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INK RETURN SYSTEM FOR A MULTIJET INK JET PRINTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention is in the field of the ink jet printers and more particularly in ink return systems for such printers.

2. Description of the Prior Art

Ink jet printers have created much interest in the area of high speed printing. For example, in computer systems, it is often desirable to print out information at speeds of up to 4,000 characters per second. Ink jet printers have this capability and may be used in conjunction with or in place of conventional CRT type display units.

In ink jet printing, one or more ink jet producing nozzles, connected to an ink reservoir through a pressure pump, receive fluid ink under pressure and eject the ink in fine continuous sprays, each of which comprises a string of droplets. The continuous ink spray inherently breaks up into very small droplets. In some systems, the rate and size of these droplets are controlled by vibrating the nozzles. The particular vibration frequency is controlled to control the size and spacing of the droplets. The stream breaks up into droplets as it passes through a charging electrode. The potential on the charging electrode is varied in accordance with the information to be printed. As the droplets pass through the electrode, a charge is transferred to the individual droplets, this charge being a function of the potential applied to the charging electrode to thereby produce information bearing droplets. Between the charging electrode and the moving printing medium upon which the information bearing droplets impinge, there is generated a fixed electrostatic field which changes the trajectory of the droplets passing therethrough, in accordance with the charge thereon, whereby the droplets are directed to selected points on the moving printing medium. An example of such a printer is illustrated in the article by R.L. Gamblin et al, Electrostatic Ink Deflection Bar Code, Printer, *IBM Technical Disclosure Bulletin*, Volume 11, No. 9, May 1969, pages 1736–1737.

Since the flow of liquid ink is continuous, a catch basin must be used to gather unused ink. The unused ink is that ink which does not carry an information indicative charge. For the purpose of describing this invention, ink jet printers will be classified into two groups, those which position the catch basin between the deflection plates and the printing medium and those in which the catch basin is integral with the deflection plates. In the former type system, exemplified by U.S. Pat. No. 3,484,793, to G.A. W. Weigl, issued Dec. 16, 1969, the droplet trajectory length is long, creating problems of aerodynamic instability of the droplets.

A technique for improving droplet stability is to shorten the trajectory path. A convenient means for accomplishing this is to make the catch basin integral with the deflection plates thereby permitting the printing medium to be placed close to the deflection plates. Such a system is described in U.S. Pat. No. 3,512,173 to D.E. Damouth, issued May 12, 1970. In the Damouth system a pair of deflection plates are associated with each nozzle, with one of the plates being placed at ground potential. The grounded deflection plate has associated therewith an intercepting plate which together with the deflection plate forms a return channel for the unused ink. A high voltage source is coupled to the other deflection plate to provide a potential difference in the area of 3000 volts between the two plates. To direct non-information bearing ink droplets into the return channel, a uniform bias charge is applied thereto. Thus each droplet, whether it carries information or not, is provided with a charge. The problem with this technique is that the charge on the unused droplets affects the charge on the information bearing droplets. Further, by requiring one of the deflection plates to be at ground potential, a separate pair of deflection plates must be utilized with each nozzle. This requirement results from manufacturing difficulties associated with the positioning of the plurality of nozzles relatively close together. Still further, very high potential sources must be used with the system.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved multi-jet, ink jet printing apparatus which includes a novel ink return system of the type which includes deflection plates formed with catch chambers integral therewith.

To accomplish the above objective, there is provided a multi-jet, ink jet printing apparatus wherein fluid ink stored in an ink reservoir is supplied under pressure to a plurality of nozzles to produce a continuous ink spray from each nozzle. A moving printing medium is positioned to receive the ink. Associated with each nozzle is a charging electrode and a pair of deflection plates. The ink ejected from the nozzles breaks up into small droplets as these droplets pass through a charging electrode. The charging electrodes are caused to assume a potential indicative of the information to be printed. When no printing is to take place, the charging electrode is placed at ground potential so that no charge is imparted to the droplets passing therethrough. As droplets pass through a charging electrode at a potential indicative of information to be printed, a charge is developed on the droplet, the charge being a function of the potential applied to the charging electrode. The droplets pass through an electrostatic field created by a pair of deflection plates whereby charged droplets impinge upon the printed medium at selected locations.

Non-information bearing droplets remain uncharged so that they do not interfere with the charge on the information carrying droplets. The deflection plates are formed with a hollow portion acting as a catch chamber for the uncharged, non-information bearing droplets. To assist in the catching of uncharged droplets, the deflection plates are disposed at a small angle with respect to the trajectory of these droplets.

Adjacent deflection plates are given respectively a positive and negative potential with respect to ground and adjacent ink jet nozzles share a common deflection plate thus reducing the total number of plates needed. For example, in a system utilizing 60 nozzles and 60 charging electrodes, only 61 deflection plates are required. In that none of the deflection plates is at ground potential, the magnitude of the potential applied to any one plate can be greatly reduced thus permitting the use of less expensive, lower potential sources. That is, instead of using for example a 3000 volt source coupled to a deflection plate, the other plate being at ground

potential, one plate is coupled to a +1500 volt source while the other plate is coupled to a −1500 volt source.

An opening is provided at the end of each deflection plate to receive fluid collected by the catch chamber. The opening is coupled to a return conduit system for carrying the unused ink back to the ink reservoir. However, as the ink enters a catch chamber, it assumes a charge which corresponds to the potential on the plate. So that the returning fluid does not provide a low resistance path between the reservoir ink at ground potential, and the deflection plates, thereby presenting a short-circuit path from the deflection plate to ground, denebulization chambers are provided within the return conduit system. As used herein denebulization refers to the breaking up of a fluid stream into relatively large drops. These chambers convert the returning substantially continuous flow of ink into relatively large drops which present a high impedance to current seeking to flow between the deflection plates and the ink reservoir.

BRIEF DESCRIPTION OF THE DRAWING

The FIGURE illustrates the improved non-shorting ink return system of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the FIGURE, information received from information sources 15 is to be printed on a printing medium 3 by selectively deflecting inking droplets produced by a plurality of nozzles 6. To this end, ink 2, stored in ink reservoir 4 is supplied in a conventional manner to the nozzles 6. Ink pump 8 is provided to introduce the ink into the nozzles 6 under pressure. The ink forced into the nozzles 6 is then ejected therefrom toward the printing medium 3. Due to the natural instability of the liquid stream 10, the ink inherently breaks up into small droplets 12 a short distance from the nozzle. In the vicinity of the ink break-up there is positioned a charging electrode 14 coupled to an information signal source 15. The information signal source provides a potential on its associated charging electrode indicative of the information which is to be printed. In its simplest form, the information signal source may be a ramp generator selectively turned on or off. As the ink droplets 12 pass through a charging electrode 14, they assume a charge which is a function of the potential on the charging electrode. The ink stream 10 is continuous and when no information is to be printed on document 3, the potential on a charging electrode 14 is at ground and thus uncharged ink droplets emerge from the charging electrode. To collect the uncharged ink droplets, each deflection plate 17 is provided with a catch chamber 16 for receiving the uncharged droplets. Each nozzle 6 is mechanically aimed at a catch chamber 16. Two deflection plates are associated with each nozzle and create a fixed electrostatic field which alters the trajectory of charged droplets. One of these plates is at a potential positive with respect to ground while the other is at a potential negative with respect to ground. To aid in the catching process, the deflection plates are positioned at a slight angle with respect to the trajectory of the droplets. As illustrated in the FIGURE, each of the deflection plates 17 is positioned at an angle of approximately 3° with respect to the trajectory of uncharged droplets.

Ink collected by the catch chambers 16 flows through openings 18 into either the return conduit 20 or 22 depending upon whether the fluid has emerged from a positive or negative potential deflection plate. The conduits may be formed of insulating material for safety reasons. However, as uncharged droplets enter a catch chamber, they assume a charge corresponding to the potential on that plate 17. Ink flows out of a deflection plate through return conduit 20 or 22 in the form of a substantially continuous flow which if it were connected would present a low resistance path between the deflection plate and the reservoir ink at ground potential. If such a low resistance path occurs, shorting out the deflection plates might result.

To prevent this, there are provided denebulization chambers 24, one coupled in line with each conduit 20 and 22. Each chamber, made of insulating material, is divided into two compartments 26 and 27. In the first compartment 26 there is provided material having a high surface tension such as metal wool. The returning ink stream enters this compartment and is emitted therefrom in large drops 28 which impinge upon a grounded conductive plate 30 in the second compartment 27. The conversion of the substantially continuous ink stream into separated large drops produces an extremely high impedance path to the deflection plate 17. In fact, the impedance between the ink reservoir 4 and the deflection plates increases to a value greater than 100 megohms. After impinging upon grounded conductive plate 30 the fluid passes through conduit 32 to the ink reservoir 4. In order to aid the return flow of ink there is provided the vacuum pump 36 to evacuate air in the reservoir 4.

To dry the denebulization chambers for preventing conduction of electrical current from taking place, each chamber 24 includes an aperture 34 through which dry air is forced using any suitable air pump (not shown). The introduction of the dry air dries the chamber thus decreasing the humidity in the chamber to prevent electrical current flow.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. In an electrostatically deflected ink-jet printer providing a continuous spray of ink droplets, a method for controlling the interception of said ink droplets with a printing medium comprising the steps of;
   a. providing deflection plates at a non-zero potential for generating an electrostatic field, each plate including a catch-chamber,
   b. imparting an electric charge to only those droplets which are to intercept said printing medium,
   c. directing the uncharged droplets to a catch-chamber
   d. breaking the ink received by the catch-chamber into drops to thereby cause the ink to form a high impedance return path to the deflection plates,
   e. passing each drop over a ground plate whereby the charge acquired by the ink upon passing through the catch-chambers of the deflection plates is neutralized and
   f. collecting the neutralized drops of ink in a reservoir.

2. The method of claim 1 further including the step of disposing said deflection plates at a slight angle with respect to the trajectory of the uncharged droplets.

3. In an electrostatically deflected ink-jet printer of the type including at least one nozzle for ejecting ink toward a printing medium, a charging electrode for selectively charging ink droplets, and an electrostatic field for deflecting the ink droplets from their trajectory an amount proportional to the charge thereon, the improvement comprising:

a. electrostatic deflection plate having a non-zero potential thereon for generating said electrostatic field, each of said deflection plates including a catch-chamber for intercepting and collecting substantially uncharged droplets, said collected droplets thereby assuming a charge dependent upon the potential of said plate,

b. a reservoir, held at substantially zero potential, for storing said ink to be fed through said at least one nozzle, and

c. a return conduit system for returning the said ink collected by said catch-chambers to said reservoir, said return conduit system comprising,

i. a container means, receiving said collected ink in a substantially continuous flow, for emitting said received collected ink in separate and discrete droplets which are relatively large compared to said ink droplets collected by said catch-chamber, to thereby result in a relatively large electrical impedance path through said ink in said return conduit system between said catch-chamber and said reservoir, and

ii. means insulating said container means from said reservoir.

4. The ink-jet printer of claim 3 wherein said deflection plates are disposed at a slight angle with resepect to the trajectory of said substantially uncharged droplets.

5. The ink jet printer of claim 3 wherein there are a plurality of nozzles, a pair of said deflection plates being associated with each nozzle, each deflection plate being either at a positive or negative potential with respect to ground, said conduit system comprising a first conduit coupled to the catch chambers of said negative potential deflection plates and a second conduit coupled to the catch chambers of said positive potential deflection plates, further including first and second of said containers for receiving ink from said conduit system, said first container receiving ink from said first conduit said second container receiving ink from said second conduit.

6. The ink jet printer of claim 5 wherein at least one plate of each pair of deflection plates associated with a nozzle forms one plate of another pair of deflection plates associated with another nozzle.

7. The ink-jet printer of claim 3 wherein each of said deflection plates is hollow, the hollow portion of the deflection plate forming the catch-chamber.

8. In an electrostatically deflected ink-jet printer of the type including at least one nozzle for ejecting ink toward a printing medium, a charging electrode for selectively charging ink droplets, and an electrostatic field for deflecting the ink droplets from their trajectory an amount proportional to the charge thereon, the improvement comprising:

a. electrostatic deflection plates having a non-zero potential thereon for generating said electrostatic field, each of said deflection plates being provided with a catch-chamber for intercepting substantially uncharged droplets;

b. an ink return conduit system receiving the ink collected by said catch-chamber,

c. a container for receiving ink from said conduit system in a substantially continuous flow, said container comprising a compartment including means for collecting the received ink and emitting it in the form of drops, so that the ink forms a high impedance return path to said deflection plates, said container further comprising another compartment including a grounded conductive plate for receiving said ink drops whereby the charge on the ink drops acquired upon passing through the catch-chambers of the deflection plates is neutralized, and

d. an ink collecting reservoir for receiving the ink drops after they pass through said container.

9. The ink-jet printer of claim 8 wherein said container is formed from non-conductive materials and wherein said compartment includes high surface tension material and said another compartment includes an inlet port for receiving dry air and an outlet port coupled to said reservoir.

10. The ink jet printer of claim 9 wherein said reservoir includes an air outlet port for connection to subatmospheric pressure and an ink outlet port for returning ink to said nozzle.

* * * * *

US005163620A

United States Patent [19]

Righi

[11] Patent Number: 5,163,620

[45] Date of Patent: Nov. 17, 1992

[54] NOZZLE FOR SUPERCONDUCTING FIBER PRODUCTION

[75] Inventor: Jamal Righi, North Canton, Ohio

[73] Assignee: The Babcock and Wilcox Company, New Orleans, La.

[21] Appl. No.: 855,141

[22] Filed: Mar. 20, 1992

Related U.S. Application Data

[63] Continuation of Ser. No. 648,462, Jan. 31, 1991, abandoned.

[51] Int. Cl.^{5} B22D 11/01

[52] U.S. Cl. 239/290; 425/7; 264/12

[58] Field of Search 239/434.5, 432, 290, 239/300; 425/7, 6; 264/112

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Primary Examiner—Andres Kashnikow
Assistant Examiner—Christopher G. Trainor
Attorney, Agent, or Firm—Vytas R. Matas; Robert J. Edwards; Daniel S. Kalka

[57] **ABSTRACT**

A nozzle apparatus for producing flexible fibers of superconducting material receives melted material from a crucible for containing a charge of the superconducting material. The material is melted in the crucible and falls in a stream through a bottom hole in the crucible. The stream falls through a protecting collar which maintains the stream at high temperatures. The stream is then supplied through the downwardly directed nozzle where it is subjected to a high velocity air flow which breaks the melted superconducting material into ligaments which solidify into the flexible fibers. The fibers are collected by blowing them against a porous cloth.

11 Claims, 4 Drawing Sheets

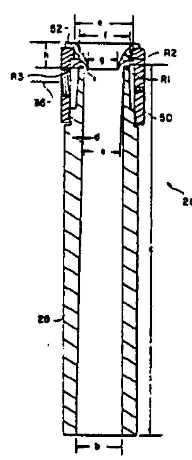

FIG. 1

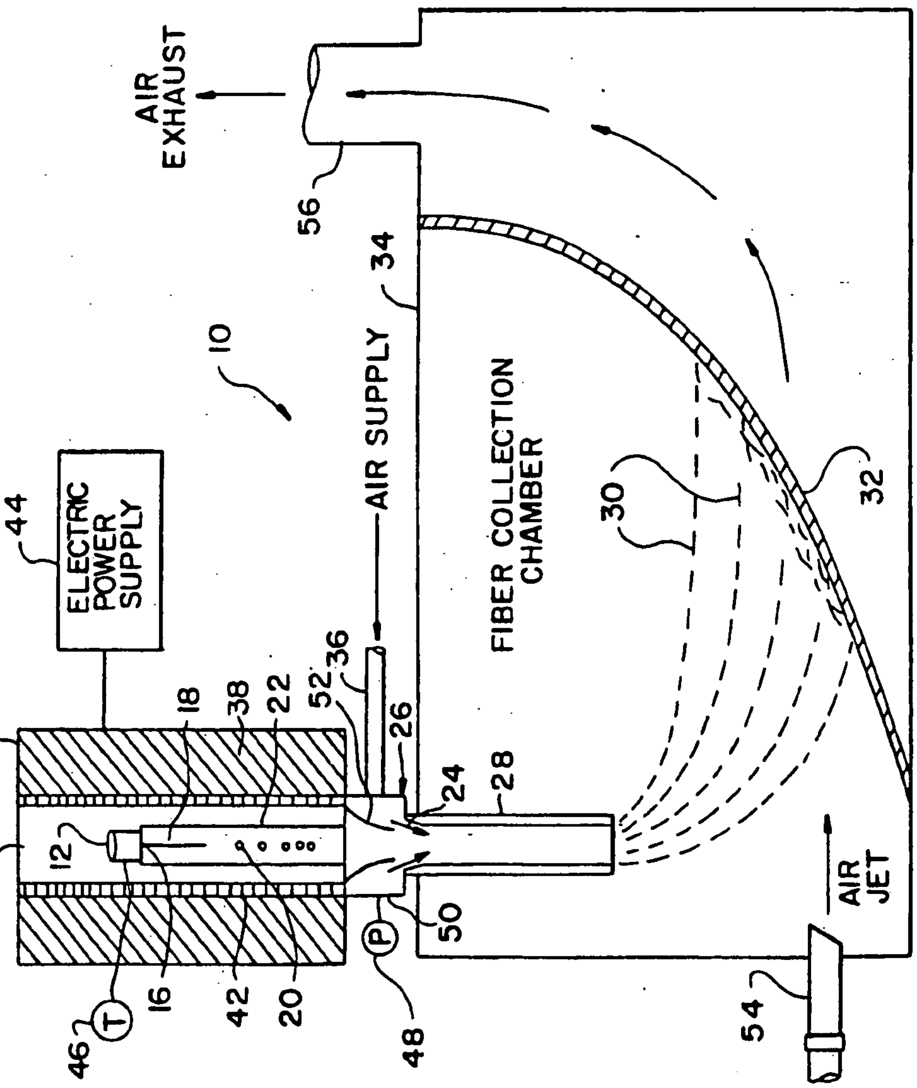
AIR EXHAUST
ELECTRIC POWER SUPPLY
AIR SUPPLY
FIBER COLLECTION CHAMBER
AIR JET
T
P
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FIG. 2

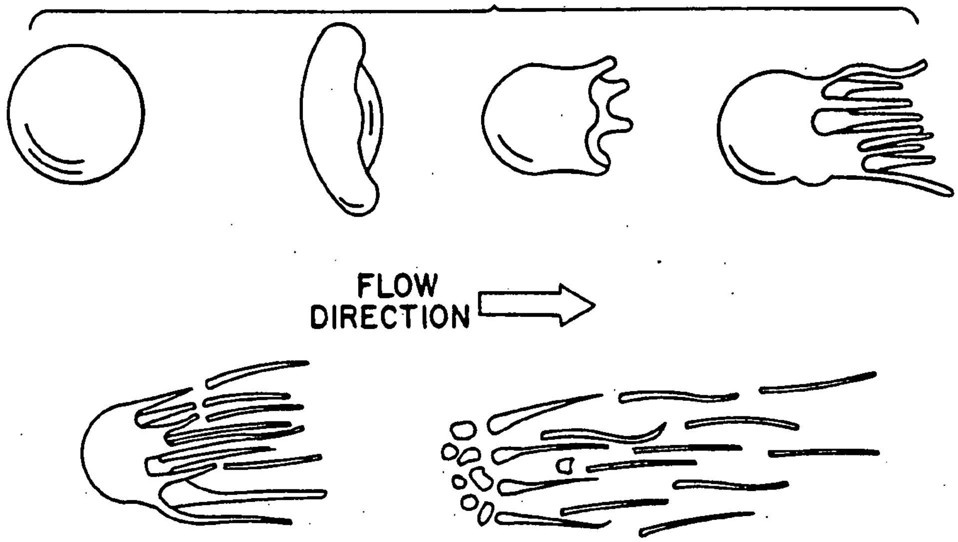
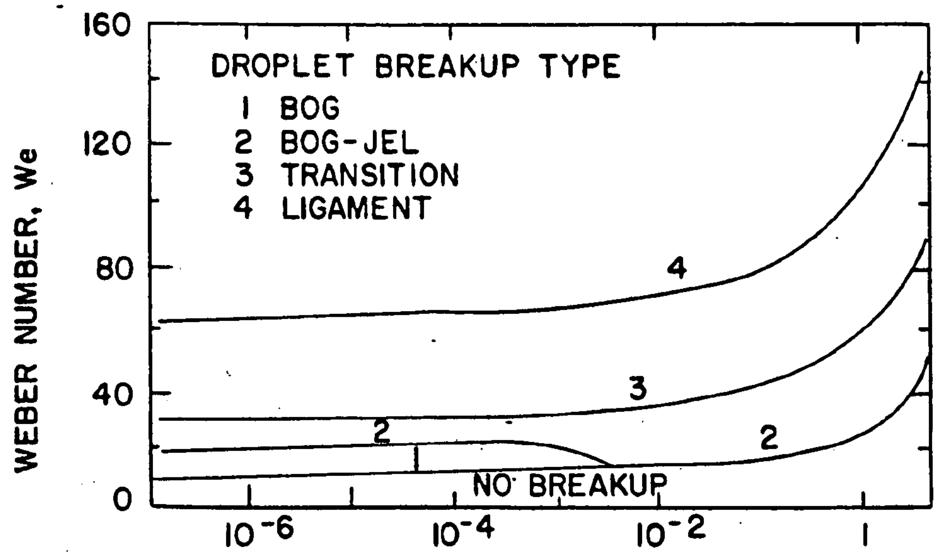

FLOW
DIRECTION

FIG. 3


DROPLET BREAKUP TYPE
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2 BOG-JEL
3 TRANSITION
4 LIGAMENT
WEBER NUMBER, We
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NO BREAKUP
4
3
2
2
10^{-6}
10^{-4}
10^{-2}
1

FIG. 4

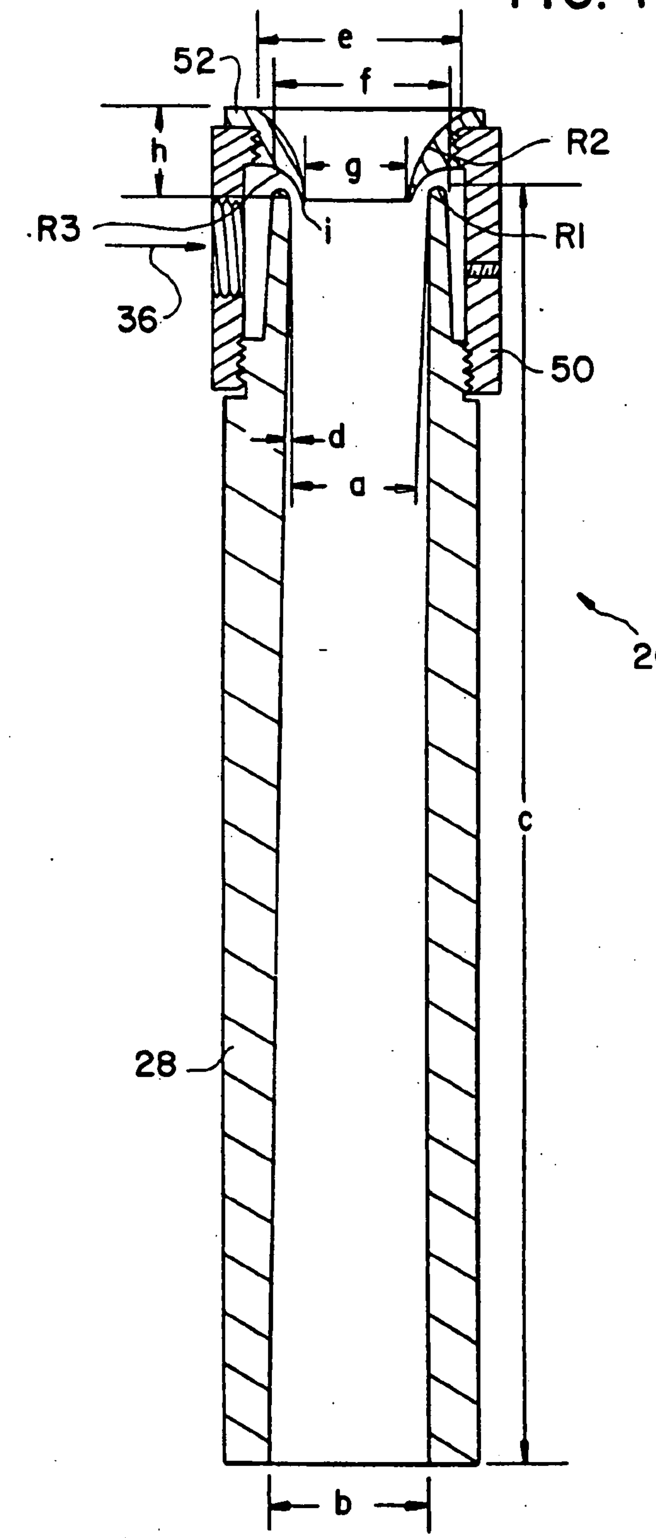
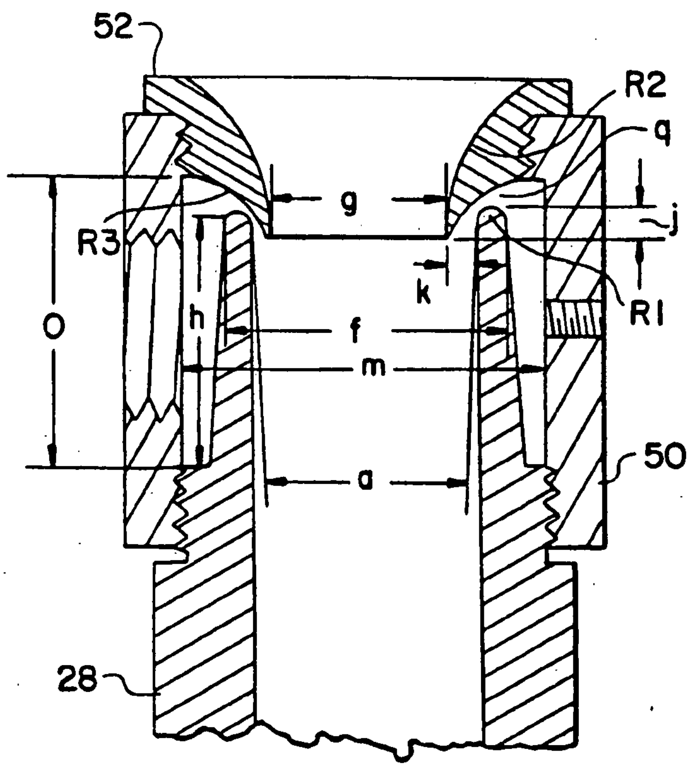


FIG. 5



NOZZLE FOR SUPERCONDUCTING FIBER PRODUCTION

This invention was made with government support under a contract with the Department of Energy (DOE) and Ames Laboratory, Contract No. SC-89-174, our Reference No. CRD-1234. The government has certain rights in this invention.

This is a continuation of application Ser. No. 07/648,462 filed Jan. 31, 1991 now abandoned.

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates in general to superconducting material, an in particular to a new and useful method and apparatus of producing elongated flexible fibers from such material.

U.S. Pat. Nos. 4,299,861 and 4,078,747 produce flexible superconductor fibers by providing a superconducting layer on a carbon fiber. U.S. Pat. No. 4,861,751 is similar in that the superconductor is formed as a sheath of superconducting oxide exterior to a core of amorphous metal alloy. U.S. Pat. No. 3,951,870 also relates to preparing a flexible superconductor fiber by the chemical conversion of a precursor carbon fiber by the high temperature reaction of a carbon yarn with a transition metal such as $NbCl_5$, H_2, N_2. U.S. Pat. No. 4,378,330 discloses a process for preparing a composite superconducting wire to form a plurality of very fine ductile superconductors in a ductile copper matrix. U.S. Pat. NO. 4,939,308 discloses an electrodeposition method for forming a superconducting ceramic. U.S. Pat. NO. 4,866,031 discloses a process for making 90° K. superconductors from acetate precursor solutions.

None of these references, however, addresses the problem of fiber brittleness where the fiber is of superconducting material only.

U.S. Pat. No. 4,828,469 to one of the coinventors here, and which is owned by the assignee of the present application, discloses an improved nozzle for the production of alumina-silica ceramic fibers. The superconducting fibers produced with this nozzle are extremely brittle.

Also, see the article entitled "Preparation of Superconducting Bi-Sr-Ca-Cu-O Fibers" by LeBeau et al., *Appl. Phys. Lett.*, 55 (3) 17 July 1989, which discloses long slender fibers of superconducting Bi compounds but which lacks the specific disclosure of the present application for creating these fibers.

Major advances have been made in the development of high-temperature superconductor (HTSC) materials based on copper-bearing oxides such as $Y_1Ba_2Cu_3O_7$ and $Bi_2Sr_2Ca_1Cu_2O_x$. These and other raw materials have been processed using a wide variety of techniques in an attempt to produce useful engineering devices. Some of the processing techniques used include plasma spraying, sputtering, sol-gel, laser pedestal growth, wire and strip manufacturing and fiberization. In the plasma spraying and sputtering methods, the HTSC material is deposited on a substrate to produce a thin film. In the laser-heated pedestal growth method, the HTSC powder is pressed into pellets and sintered and small rods are cut from the pellets. A laser is used to melt the top of the rod and a seed crystal is placed in the melt. The wire is grown by withdrawing the seed at a controlled rate between 1.5 and 50 mm/hr. This method is extremely slow and therefore does not lend itself to becoming a good technique for mass production. In the fiberization method, Bismuth based compounds were melted and fiberized using a gas jet. Fibers typically 100 μm to 200 μm in diameter and 5 mm to 10 mm in length were produced using the nozzle of U.S. Pat. No. 4,828,465. The fibers were very brittle and did not have a large length-to-diameter ratio, however. Small pieces of thin film, strip, tape and wire have been produced from the superconducting materials. However, methods and apparatus still need to be developed to put the small pieces of wire and tape into commercially-useful HTSC devices. These materials are not produced in bulk quantities and continue to suffer from the problems of brittleness, which are hampering the transfer of production from the laboratory to industry.

SUMMARY OF THE INVENTION

A main object of the present invention is to provide high-temperature superconducting (HTSC) fibers with better mechanical properties (flexibility) than currently available. The flexibility makes these fibers more useful in producing multi-filamentary superconducting composite wires which can be used in many commercial applications. The composite superconducting wires require fibers with diameters on the order of a few microns and length-to-diameter ratios in the range of 1,000 to 10,000. The fine fibers produced from HTSC materials are incorporated into a normal metal matrix to form the composite multi-filamentary conductor. Davidson, Tinkham and Beasley (IEEE Trans. Magn. MAG-11, 276, 1975) have shown that the effective conductivity of such a superconductor-normal metal composite is increased over the normal metal conductivity by the square of the length-to-diameter ratio of the fibers, $[\sigma \sim 1/d^2]$. This means that a composite of superconducting filaments 1 cm long and 10 μm in diameter embedded in a copper matrix will give a conductivity one million times greater than that of copper alone. If, in addition, there is a significant proximity effect, in which superconductivity is induced in the copper matrix, true supercurrents will flow. The goal here is to develop a process for the preparation of long slender fibers of the high temperature superconductors for use in those composites.

Accordingly, another object of the present invention is to provide a method of producing flexible fibers of superconducting material, comprising: melting a superconducting material; dropping a stream of the melted superconducting material into a vertically extending barrel; blowing gas downwardly through the barrel at a sufficient rate to transform the melted superconducting material in the barrel, into fine ligaments which cool and solidify in the barrel to form flexible fibers; and collecting the flexible fibers.

A further object of the present invention is to provide an apparatus for producing flexible fibers of superconducting material which comprises a nozzle of special construction and design which has been found to be critical for producing the flexible superconducting fibers.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the invention, its operating advantages and specific objects attained by its uses, reference is made to the accompanying drawings and descriptive matter in which the preferred embodiments of the invention are illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a schematic sectional view of an apparatus constructed in accordance with the present invention, for practicing the method of the present invention;

FIG. 2 is a time elapse, composite view of how a droplet deforms under the influence of the gas stream in a barrel of the blowing nozzle;

FIG. 3 is a graph plotting, the inverse of the LaPlace number against the Weber number for droplet breakup mechanisms;

FIG. 4 is a sectional view of the nozzle constructed in accordance with the present invention; and

FIG. 5 is a partial sectional view of the nozzle, on an enlarged scale.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings in particular, the invention embodied in FIG. 1 comprises an apparatus generally designated 10 for producing flexible fibers of superconductor material 30, in accordance with the method of the present invention.

$Bi_2Sr_2Ca_1Cu_2O_x$ (Bi 2212) high-temperature superconducting material in powder form is melted in an alumina crucible 12 using an electric furnace 14 of the apparatus 10. The Bi 2212 melts completely at 1650° F. (phase change). The melt, however, is superheated to 1720°-1740° F. to reduce its viscosity. Once the melt is well established, it flows freely at 18 from a small hole 16 at the bottom of the alumina crucible 12. The melt forms a continuous stream which might break up into separate droplets at 20. The melt falls through a high-temperature ceramic collar 22 in the furnace, which is used to stabilize the melt stream and prevent it from wavering. The molten stream is then subjected to a high velocity fiberizing air stream 24 inside a blowing nozzle 26 mounted in the vertical direction. The high velocity air generates enormous shearing rates on the surface of the molten stream which transform the Bi 2212 melt into fine ligaments. The ligaments in the molten/glassy state undergo further shearing and cooling inside a barrel 28 of the nozzle 26. The filaments become long and thin and reach complete solidification producing fibers 30. Some of the melt produces small flakes and nearly spherical shot. The blown material is collected downstream on a porous cloth 32 in a vented collecting chamber 34. The blowing nozzle 26 is a modification of the nozzle in U.S. Pat. No. 4,828,469. The modified nozzle is here designed specifically to accommodate the thermal and fluid characteristics of the Bismuth-based superconductor melts; namely, to match the viscous behavior and cooling characteristics of these melts. Furthermore, the new nozzle is designed to bring the high velocity shear layer in close proximity of the droplets so that fine fibers are stripped from the melted superconducting material. The objective of the modified nozzle is to obtain thin fibers with length-to-diameter ratios in the range of 1,000 to 10,000. The produced fiber is very flexible and ranged in diameter from 1 to 10 microns (μm) with lengths of about 25 to 50 millimeters. The nozzle is operated at supersonic speeds and with an air supply 36 sufficient to produce pressures between 10 and 20 psig for best results.

The present invention addresses one of the major obstacles facing the development of high-temperature superconductors; namely, the problem of brittleness. Most of the materials produced from HTSC powders exhibit poor mechanical properties and therefore cannot be used reliably in commercially-useful devices. In addition, these materials have only been produced in simple shapes, such as small pieces of wire, tape and thin film and methods of mass production are still lacking. The flexible fibers of the invention can reliably be made on a mass production basis using the gas jet blowing technique.

The major advantages of the present invention are that: the fibers formed from the HTSC material are very flexible which permits the formation of rope and other forms of fiber bundles which can be flexibly shaped into useful applications, such as for motors, generators, transformers, magnets, power lines, levitated trains and medical imaging systems.

Long slender fibers are an attractive shape for a superconducting material because they can be combined into a superconducting-normal metal composite having an enormous overlap area for current transfer between fibers. Also the 1-10 micron (μm) diameters and length-to-diameter ratios of 1,000 to 10,000 of these fibers are ideal for the development of multi-filamentary superconducting wire.

Although the present invention has been described in terms of the Bismuth 2212 HTSC material, fibers can also be produced from the Bismuth 1112, lead-bearing bismuth compounds and other non-bismuth-based materials. Newly-developed and existing superconducting material could also be suitable candidates for the production of flexible fibers as long as they possess the appropriate thermal and fluid properties for good fiberization.

Returning now to FIG. 1, the apparatus 10 includes an insulated sleeve of high temperature refractory material 38 which contains a central passage 40 in which the crucible 12 and collar 22 are positioned. This chamber is surrounded by a heating coil 42 which is connected to an electric power supply 44, for heating the crucible and collar to the melting temperatures of the material in the crucible and above.

A temperature sensor 46 is advantageously connected to the crucible 22 for sensing the temperature of the crucible, and a pressure sensor 48 is connected to an inlet chamber 50 of the nozzle 26. A converging deflector or disc 52 is positioned within inlet chamber 50 for deflecting the air supply 36 downwardly in the direction of flow 24, for transforming the stream droplets 20 into ligaments which solidify in the barrel 28 and form fibers 30.

A collecting air or gas supply line 54 also directs air or other gas against the collecting cloth 32. This air is vented from the collecting chamber 34 through an exhaust 56.

In practicing the present invention, it was found that the temperature of the superconducting material in the crucible must be raised up to 100° above its melting point to ensure that the melt is sufficiently fluid to flow through the opening in the crucible 12. Only after the higher temperature range was reached, was a plug (not shown) in the opening 16 removed to initiate the stream 18.

It was also important to investigate droplet formation. There are several distinct mechanisms for droplet breakup depending on the value of the Weber number (We) and LaPlace number (La) which are expressed by

$$We=(\rho_1 U^2 D)/\sigma \qquad 1)$$

$$1/La=\mu^2/\sigma\rho D \qquad 2)$$

where ρ_a is the air density, U is the local air velocity, σ is surface tension, ρ is melt density, μ is melt viscosity and D is the diameter of the undisturbed droplet. The Weber number is the ratio of the aerodynamic force to the droplet surface tension and the inverse LaPlace number is the ratio of the viscous force to the surface tension force on the droplet.

The manner in which liquid droplets disintegrate is found to depend on the range of the Weber number as shown in FIG. 3. For Weber numbers under about 10 there is no breakup; between about 10 and 25 there is a bag mode; between 25 and 50 there is an umbrella mode; between 50 and about 1000 there is a stripping of ligaments from the periphery of the deformed droplet; above 1000, atomization begins. Ligament type breakup is desirable for fiber production because it yields more fibers and less shot. FIG. 2 shows the ligament mode breakup. For this reason, the liquid does not solidify until the last stage where filaments and shot of the high temperature superconductor are formed. For 1/La less than 0.01, ligament formation and fiberization requires a Weber number in the range of 70, and the effect of the LaPlace number was found experimentally to be small as shown in FIG. 3. For inverse LaPlace numbers greater than 0.01, the Weber number must be somewhat larger to achieve fiberization.

According to the invention, in addition to reducing the viscosity of the melted superconducting material, down to about 1 poise at the superheated level, it is also important to utilize a nozzle 26 of particular dimensions and design which have been found by the inventors to be critical.

Referring now to FIGS. 4 and 5, nozzle 26 is structurally similar to the nozzle disclosed in U.S. Pat. No. 4,828,469, which was mentioned above, however the inventors have found that a careful selection of the relative dimensions and positions for the elements of the nozzle are critical to forming superconducting fibers that are flexible and which also have the desired length-to-diameter ratio. The nozzle is designed specifically to accommodate the thermal and fluid characteristics of the Bismuth-based superconductor melts, namely to match the viscous behavior and cooling characteristic of these melts. The Bismuth-based and other high temperature superconductor materials have a relatively narrow fiberization temperature window due to the sharp change of melt viscosity with temperature compared to glasses and alumina-silica melts. Therefore, the nozzle of the present invention is placed in the vertical direction immediately beneath the furnace to prevent the melt stream/droplets from cooling before they reach the blowing nozzle 26.

Furthermore, the nozzle of the present invention is designed to bring the high velocity shear layer of air in close proximity to the droplets so that fine fibers are stripped from the melted superconducting material as illustrated in FIG. 2.

Returning now to FIGS. 4 and 5, the various dimensions which are illustrated in the Figures have been found to have the following optimum values, for making flexible fibers of superconducting material having the desired characteristics setforth in this disclosure:

Barrell inside inlet diameter	a = 1.25"

-continued

Barrell inside outlet diameter	b = 1.60"
Barrell length	c = 13.80"
Barrell bore taper angle	d = 0.73°
Disc inside inlet diameter	e = 2.00"
Barrel outside inlet diameter	f = 1.61"
Disc inside outlet diameter	g = 1.102"
Disc axial length	h = 0.844"
Disc minimum annular outlet thickness	i = 0.040"
Axial overlap between disc and barrel	j = 0.140"
Radial annular gap between disc outlet and barrel	k = 0.034"
Air chamber inside diameter	m = 2.09"
Axial length of barrel in air chamber	n = 1.67"
Chamber axial length	o = 1.82"
Minimum annular gap between disc and barrel	q = 0.02"
Radius of barrel inlet end	R1 = 0.09"
Disc inlet passage radius	R2 = 1.50"
Disc outside radius	R3 = 0.344"

Of these measurements, the most critical is the minimum annular gap q of about 0.02" which has been found to be particularly instrumental in achieving the fibers of the desired characteristics. The other dimensions are also important.

While a specific embodiment of the invention has been shown and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. A nozzle for producing flexible fibers of high temperature superconducting material, comprising:
   - a deflector disc having a passage therethrough with an inlet end for receiving melted superconducting material from a crucible, and an outlet end, said passage decreasing smoothly and continuously from said inlet end to said outlet end;
   - a barrel having an inlet end extending around the outlet end of said disc and defining an annular gap of about 0.02" between said disc and the inlet end of said barrel; and
   - a housing around said disc and around the inlet end of said barrel defining an air chamber around the inlet end of said barrel for receiving air which passes through said annular gap into said barrel, said housing being positioned immediately beneath a furnace containing the crucible so as to place said inlet end of said deflector disc vertically beneath the crucible to prevent the melted superconducting material from cooling when it passes therethrough, wherein the nozzle receives the melted superconducting material to produce flexible superconducting fibers having diameters of from about 1 to 10 microns and length-to-diameter ratios of from about 1,000 to 10,000.

2. A nozzle according to claim 1, wherein the outlet end of said disc axially overlaps the inlet end of said barrel by about 0.140".

3. A nozzle according to claim 2, wherein the outlet end of said disc radially overlaps the inlet end of said barrel by about 0.034".

4. A nozzle according to claim 1, wherein said inlet end of said deflector disc has a diameter of about 2 inches.

5. A nozzle according to claim 1, wherein said outlet end of said deflector disc has a diameter of about 1.102 inches.

6. A nozzle according to claim 1, wherein said inlet end of said barrel has a diameter of about 1.25 inches.

7. A nozzle according to claim 1, wherein said barrel further comprises an outlet end having a diameter of about 1.60 inches.

8. A nozzle according to claim 1, wherein said barrel has a length of about 13.80 inches.

9. A nozzle according to claim 1, wherein said barrel further comprises a bore having a taper angle of about 0.73°.

10. A nozzle according to claim 1, wherein said deflector disc includes a bore being defined by a continuous circumferential surface having a radius in axial cross-section of about 1.50 inches.

11. A nozzle according to claim 1, further comprising an air supply for supplying air to the air chamber around the inlet end of said barrel to produce a pressure between about 10 and 20 psig.

* * * * *

US005759961A

United States Patent [19]

Zeigler et al.

[11] **Patent Number: 5,759,961**

[45] **Date of Patent: Jun. 2, 1998**

[54] **SUPERCONDUCTOR FIBER ELONGATION WITH A HEATED INJECTED GAS**

[75] Inventors: **Douglas D. Zeigler**, Atwater; **Barry L. Conrad**, Alliance; **Richard A. Gleixner**, North Canton, all of Ohio

[73] Assignee: **The Babcock & Wilcox Company**, New Orleans, La.

[21] Appl. No.: **921,821**

[22] Filed: **Jul. 29, 1992**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 648,461, Jan. 31, 1991, abandoned.

[51] **Int. Cl.**[6] **B22D 11/01**

[52] **U.S. Cl.** **505/950**; 065/525; 264/14; 425/7; 425/72.2; 425/74; 505/704

[58] **Field of Search** 65/507, 510, 524, 65/525, 526; 239/290, 300, 432, 434.5; 264/12, 13, 14; 425/6, 7, 72.1, 72.2, 73, 74; 505/704, 950

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5,171,489	12/1992	Hirao et al.	264/12

Primary Examiner—C. Scott Bushey

Attorney, Agent, or Firm—Daniel S. Kalka; Robert J. Edwards

[57] **ABSTRACT**

An improved method and apparatus for producing flexible fibers (**30**) of superconducting material includes a crucible (**12**) for containing a charge of the superconducting material. The material is melted in the crucible (**12**) and falls in a stream (**18**) through a bottom hole (**16**) in the crucible (**12**). The stream (**18**) falls through a protecting collar (**22**) which maintains the stream (**18**) at high temperatures. The stream (**18**) is then supplied through a downwardly directed nozzle (**26**) where it is subjected to a high velocity of a heated gas (**36'**) which breaks the melted superconducting material into ligaments which solidify into the flexible fibers (**30**). The fibers (**30**) are collected by directing them against a collection filter (**32**).

8 Claims, 7 Drawing Sheets

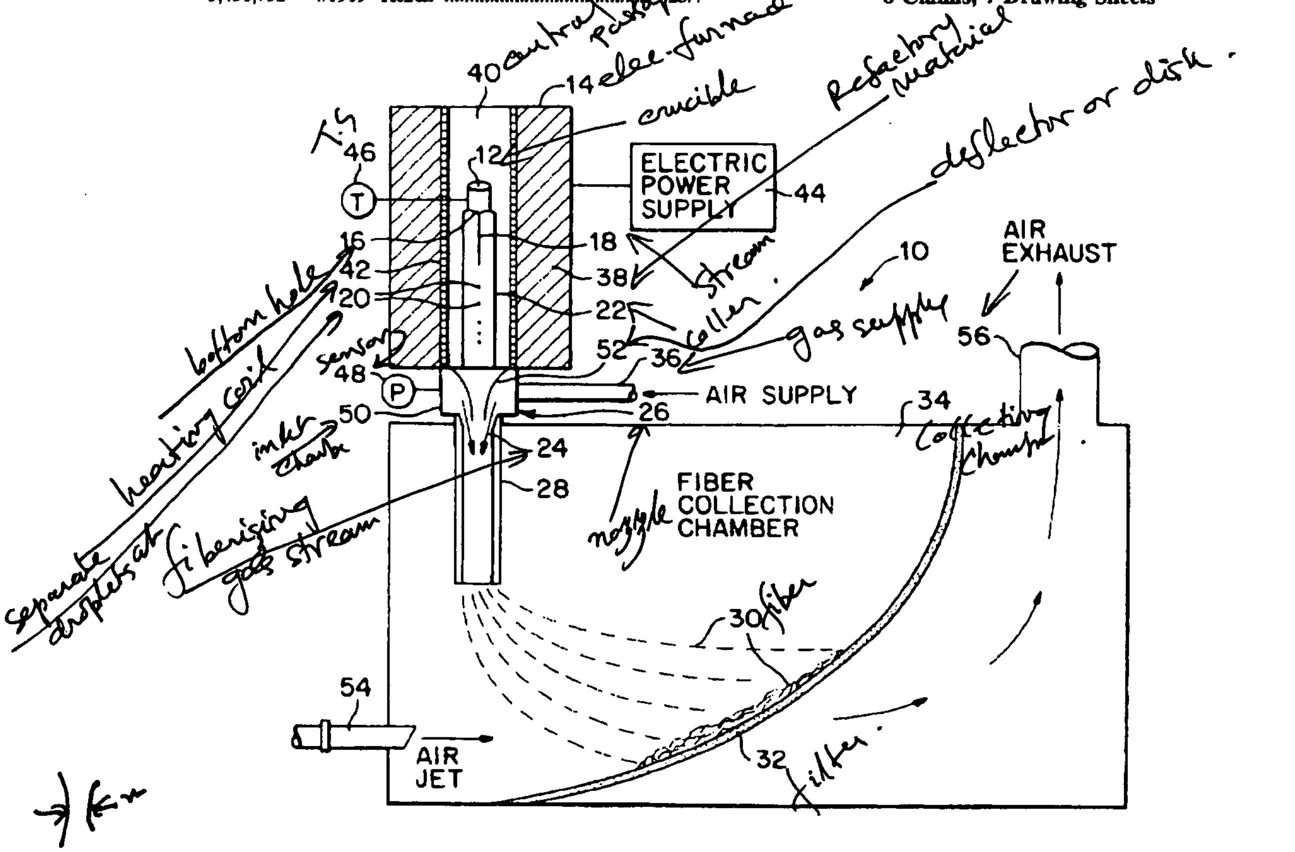
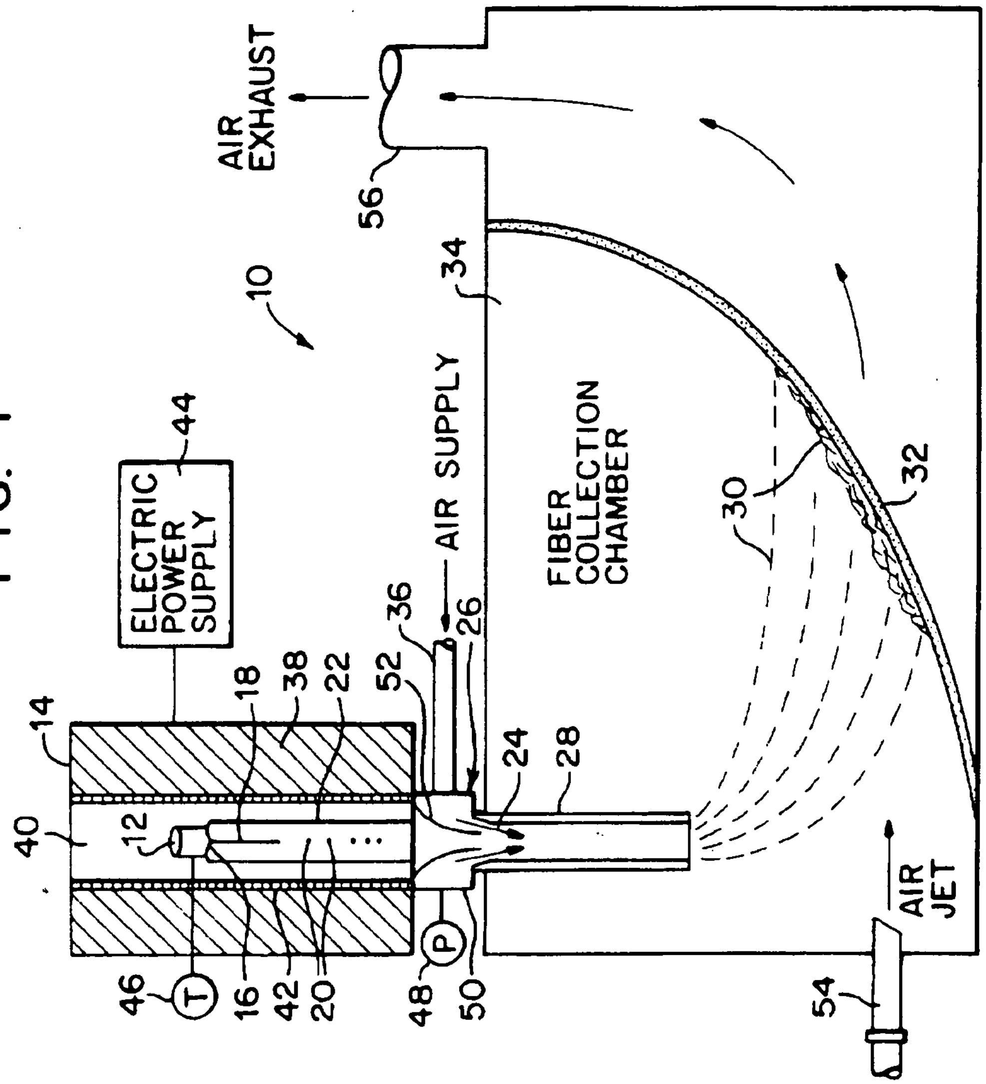


FIG. 1


ELECTRIC POWER SUPPLY
AIR SUPPLY
FIBER COLLECTION CHAMBER
AIR EXHAUST
AIR JET
T
P
10
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16
18
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52
54
56

FIG. 2

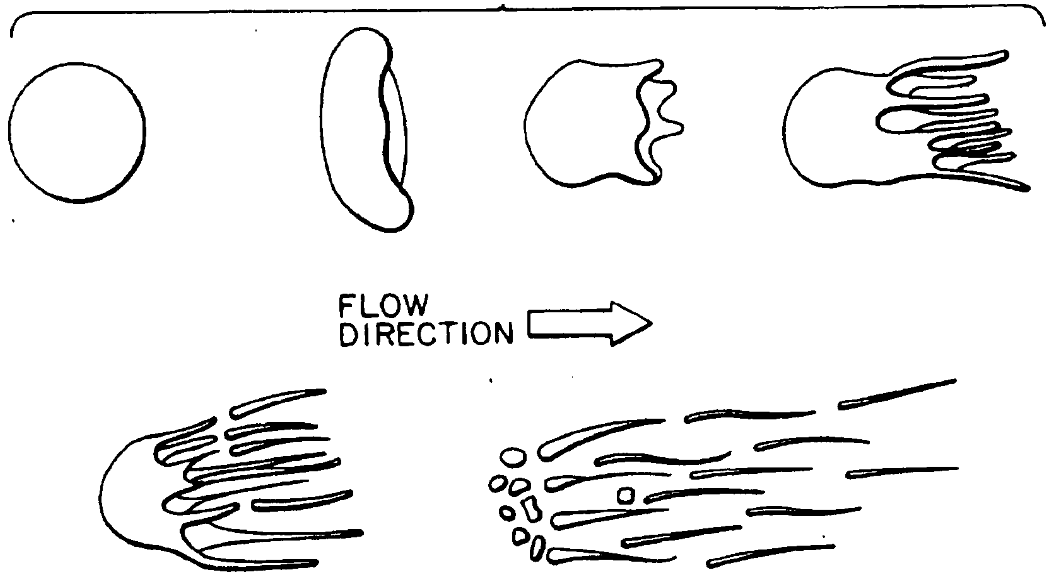

FLOW
DIRECTION

FIG. 3

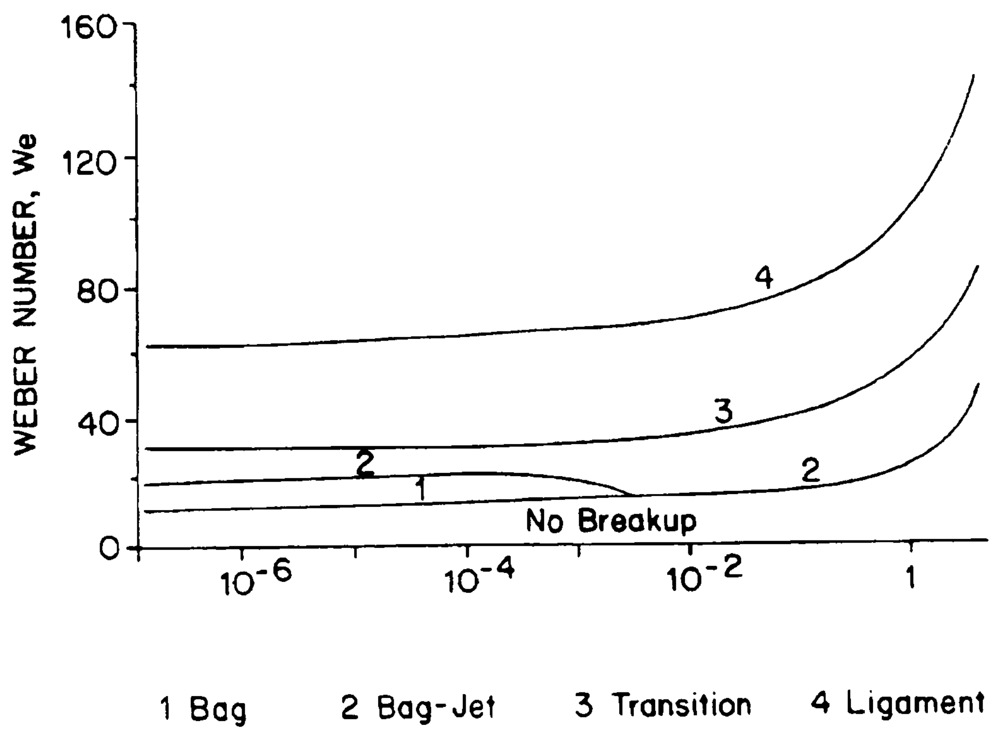

160
120
80
40
0
WEBER NUMBER, We
4
3
2
2
1
No Breakup
10^{-6}
10^{-4}
10^{-2}
1
1 Bag
2 Bag-Jet
3 Transition
4 Ligament

FIG. 4

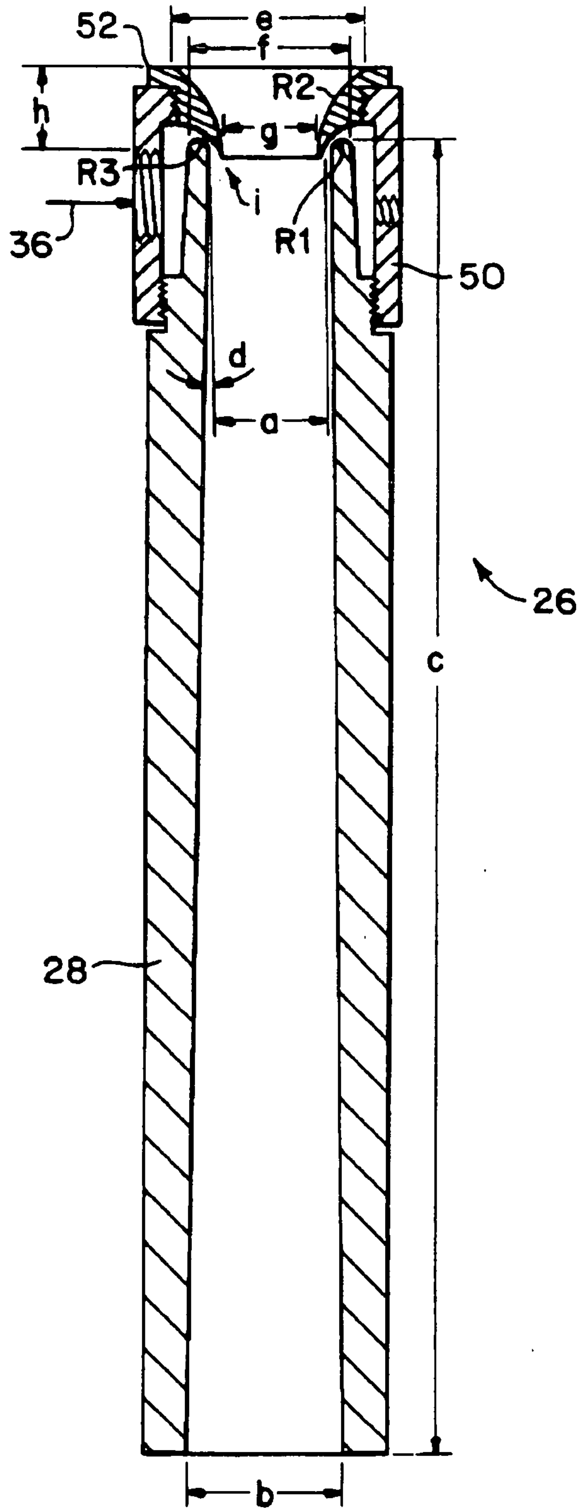


FIG. 5

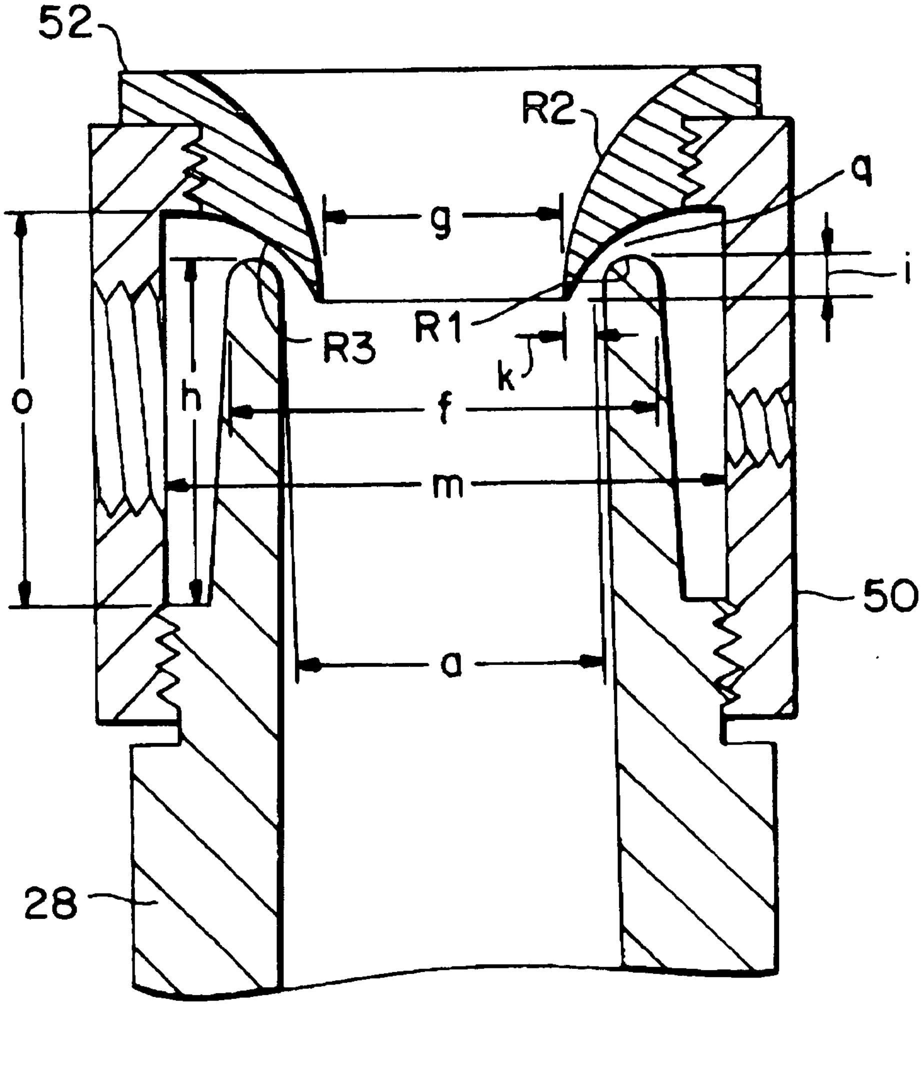
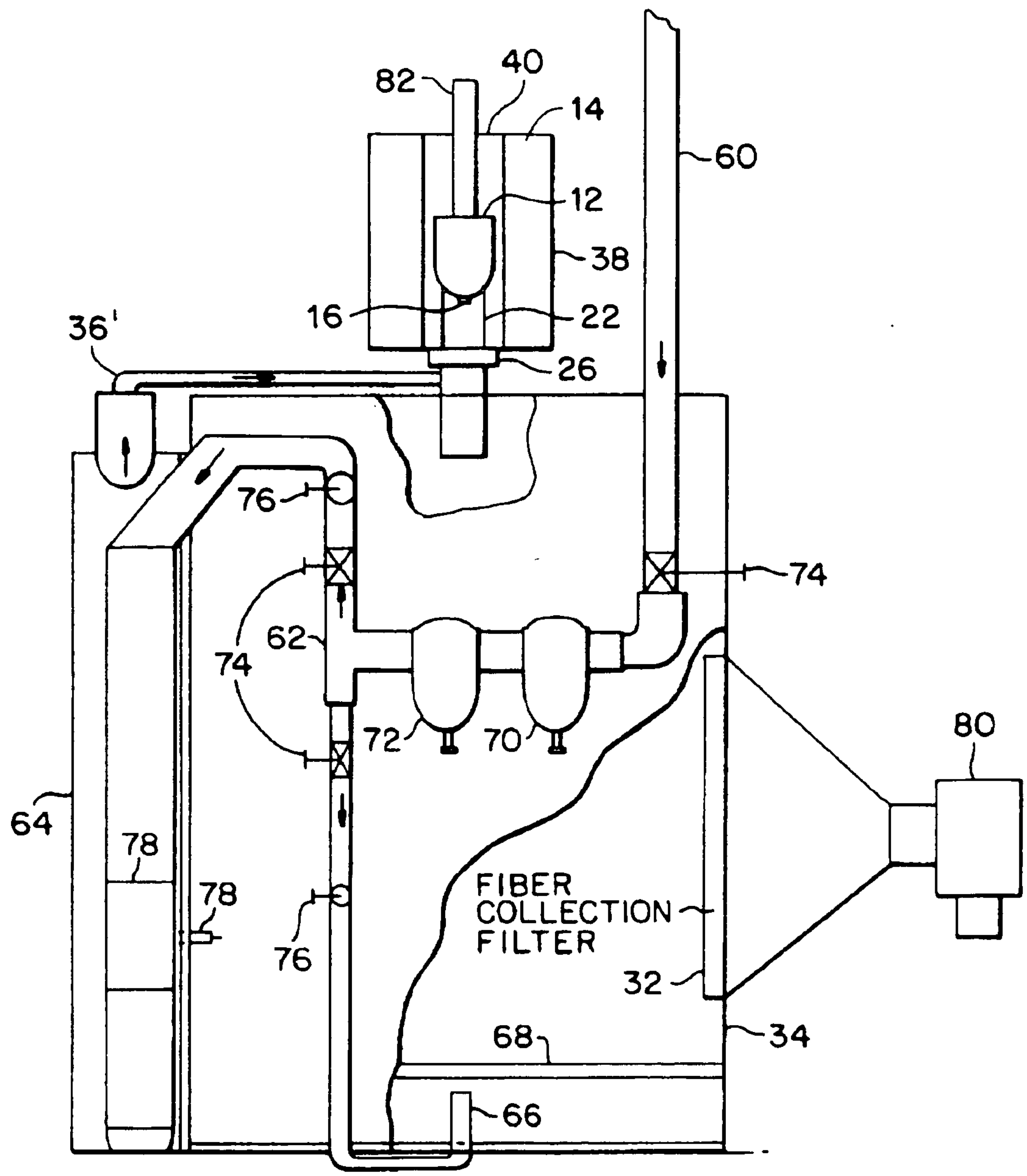


FIG. 6


82
40
14
60
12
38
36'
16
22
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74
62
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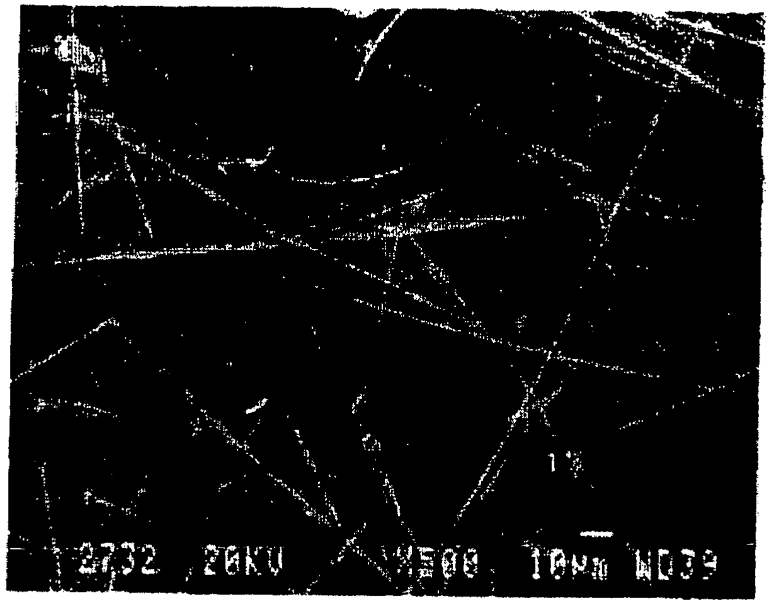
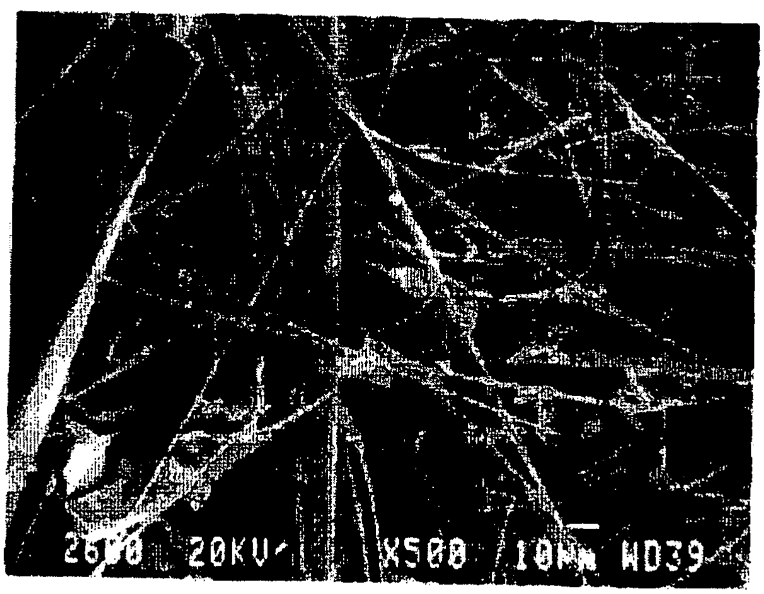
72
70
80
64
78
78
FIBER
COLLECTION
FILTER
76
32
34
68
66



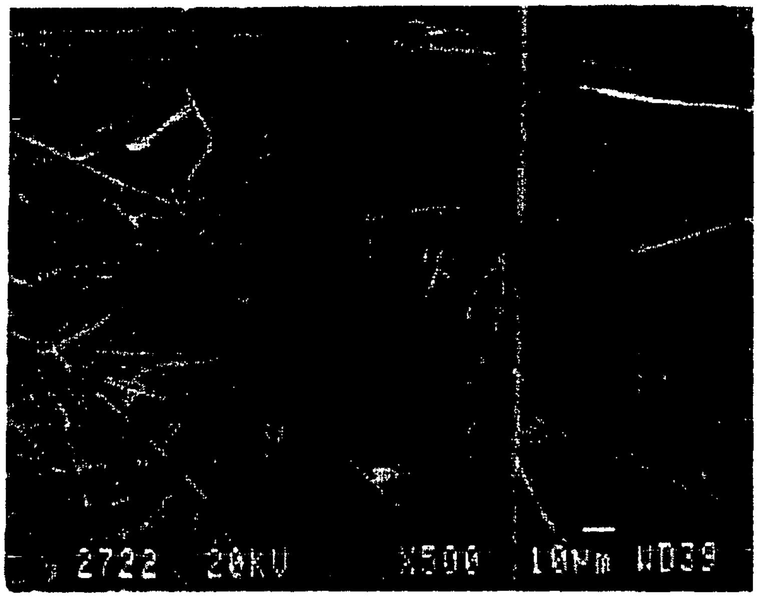
Fibers Produced with 260°C Air (500X).

FIG.7



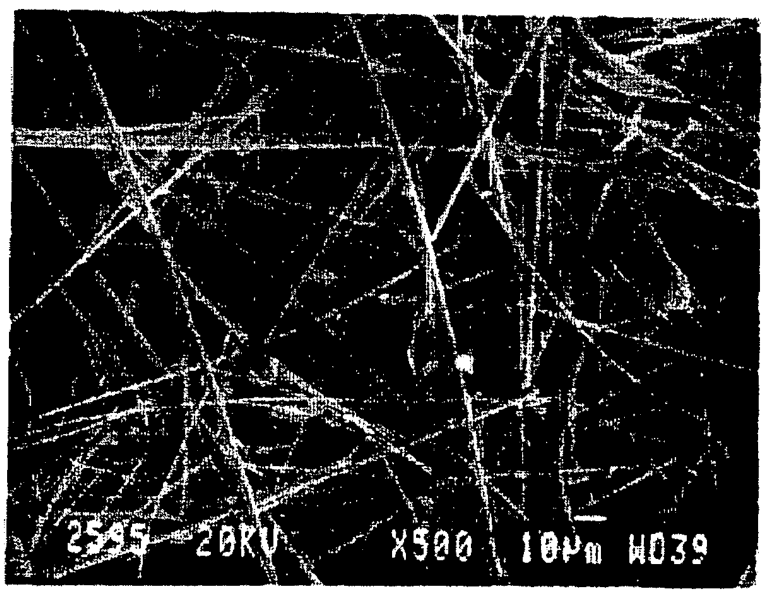
Fibers Produced With Ambient Air (500X).

FIG.8



Fibers Made With Argon Gas

FIG. 9



Fibers Made with Helium Gas

FIG. 10

SUPERCONDUCTOR FIBER ELONGATION WITH A HEATED INJECTED GAS

This application is a continuation-in-part of U.S. patent application Ser. No. 07/648,461, filed Jan. 31, 1991, now abandoned.

This invention was made with Government support under a contract with the Department of Energy (DOE) and Ames Laboratory, Contract No. SC-91-225, our reference number CRD-1272. The Government has certain rights in this invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates in general to superconducting material, and in particular to a new and improved method and apparatus of producing elongated flexible fibers from such material.

2. Description of the Related Art

U.S. Pat. Nos. 4,299,861 and 4,078,747 produce flexible superconductor fibers by providing a superconducting layer on a carbon fiber. U.S. Pat. No. 4,861,751 is similar in that the superconductor is formed as a sheath of superconducting oxide exterior to a core of amorphous metal alloy. U.S. Pat. No. 3,951,870 also relates to preparing a flexible superconductor fiber by the chemical conversion of a precursor carbon fiber by the high temperature reaction of a carbon yarn with a transition metal such as $NbCl_5$, H_2, N_2. U.S. Pat. No. 4,378,330 discloses a process for preparing a composite superconducting wire to form a plurality of very fine ductile superconductors in a ductile copper matrix. U.S. Pat. No. 4,939,308 discloses an electrodeposition method for forming a superconducting ceramic. U.S. Pat. No. 4,866,031 discloses a process for making 90° K. superconductors from acetate precursor solutions.

None of these references, however, addresses the problem of fiber brittleness where the fiber is of superconducting material only.

U.S. Pat. No. 4,828,469, which is owned by the assignee of the present application, discloses an improved nozzle for the production of alumina-silica ceramic fibers. The fibers from superconducting material produced with this nozzle are extremely brittle.

Also, see the article entitled "Preparation of Superconducting Bi-Sr-Ca-Cu-O Fibers" by LeBeau, et al., *Appl. Phys. Lett.*, 55 (3) 17 Jul. 1989, which discloses long slender fibers of superconducting Bi compounds but which lacks the specific disclosure of the present application for creating these fibers.

Major advances have been made in the development of high-temperature superconductor (HTSC) materials based on copper-bearing oxides such as $Y_1Ba_2Cu_3O_7$ and $Bi_2Sr_2Ca_1Cu_2O_X$. These and other raw materials have been processed using a wide variety of techniques in an attempt to produce useful engineering devices. Some of the processing techniques used include plasma spraying, sputtering, sol-gel, laser pedestal growth, wire and strip manufacturing and fiberization. In the plasma spraying and sputtering methods, the HTSC material is deposited on a substrate to produce a thin film. In the laser-heated pedestal growth method, the HTSC powder is pressed into pellets and sintered and small rods are cut from the pellets. A laser is used to melt the top of the rod and a seed crystal is placed in the melt. The wire is grown by withdrawing the seed at a controlled rate between 1.5 and 50 mm/hr. This method is extremely slow and therefore does not lend itself to becoming a good technique for mass production.

In the fiberization method, Bismuth based compounds were melted and fiberized using a gas jet. Fibers typically 100 μm to 200 μm in diameter and 5 mm to 10 mm in length were produced using the nozzle from U.S. Pat. No. 4,828,469. The fibers were very brittle and did not have a large length-to-diameter ratio, however. Small pieces of thin film, strip, tape and wire have been produced from the superconducting materials.

With the development of gas fiberization techniques by The Babcock & Wilcox Company, the preparation of the high temperature superconductor $Bi_2Sr_2Ca_1Cu_2O_8$ from the melt became possible. The advantage of such an approach over commonly utilized powder sintering processes is that the material produced is (for practical purposes) amorphous with excellent ductility. Transformation of the amorphous product by crystallization via thermal treatment can be achieved reliably. Also, much higher densities than can be achieved from conventional processing are observed for the fiber material. A higher integrity structure with better current transport properties can be manufactured from such a starting stock material.

It is desirable with such a gas fiberization technique to complete the transformation of the molten droplet to a completely full length fiber by allowing the feeder ball droplet to stay molten until complete fiber transformation is completed.

SUMMARY OF THE INVENTION

The present invention solves the aforementioned problem as well as others by providing a heater which provides heated gas into the primary gas side of the fiberization nozzle. The gas temperature is adjusted to match the type of material intended to be fiberized.

One object of the present invention is to provide high-temperature superconductor (HTSC) fibers with better mechanical properties (flexibility) than currently available. The flexibility makes these fibers more useful in producing multi-filamentary superconducting composite wires which can be used in many commercial applications. The composite superconducting wires require fibers with diameters on the order of a few microns and length-to-diameter ratios in the range of 1,000 to 10,000. The fine fibers produced from HTSC materials are incorporated into a normal metal matrix to form the composite multi-filamentary conductor. Davidson, Tinkham and Beasley (IEEE Trans. Magn. MAG-11, 276, 1975) have shown that the effective conductivity of such a superconductor-normal metal composite is increased over the normal metal conductivity by the square of the length-to-diameter ratio of the fibers, $[\sigma \sim 1/d^2]$. This means that a composite of superconducting filaments 1 cm long and 10 cm in diameter embedded in a copper matrix will give a conductivity one million times greater than that of copper alone. If, in addition, there is a significant proximity effect, in which superconductivity is induced in the copper matrix, true supercurrents will flow. The goal here is to develop a process for preparation of long slender fibers of the high temperature superconductors for use in those composites.

Accordingly, another object of the present invention is to provide a method of producing flexible fibers of superconducting material, comprising: melting a superconducting material; dropping a stream of the melted superconducting material into a vertically extending barrel; blowing a heated gas downwardly through the barrel at a sufficient rate to transform the melted superconducting material in the barrel.

into fine ligaments which form flexible fibers; and collecting the flexible fibers.

A further object of the present invention is to provide an apparatus for producing flexible fibers of superconducting material which comprises a heater providing heated gas into the primary gas side of a nozzle of special construction and design which has been found to be critical for producing the flexible superconducting fibers.

Still a further object of the present invention is to provide a method and apparatus which completes the transformation of a molten droplet in a gas fiberization technique to a completely full length fiber by allowing the feeder ball droplet to stay molten until complete fiber transformation is completed.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the invention, its operating advantages and specific objects attained by its uses, reference is made to the accompanying drawings and descriptive matter in which the preferred embodiments of the invention are illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a schematic sectional view of an apparatus constructed in accordance with the present invention, for practicing the method of the present invention;

FIG. 2 is a time elapse, composite view of how a droplet deforms under the influence of the gas stream in a barrel of the blowing nozzle;

FIG. 3 is a graph plotting, the inverse of the LaPlace number against the Weber number for droplet breakup mechanisms;

FIG. 4 is a sectional view of the nozzle constructed in accordance with the present invention;

FIG. 5 is a partial sectional view of the nozzle, on an enlarged scale;

FIG. 6 is a schematic view with portions removed of the preferred embodiment in accordance with the present invention for practicing the method of the present invention;

FIG. 7 is a photomicrograph of fibers produced with heated fiberization air;

FIG. 8 is a photomicrograph of fibers produced with ambient air;

FIG. 9 is a photomicrograph of fibers made with argon gas; and

FIG. 10 is a photomicrograph of fibers made with helium gas.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings in particular, one embodiment of the invention shown in FIG. 1 comprises an apparatus generally designated (10) of producing a flexible fibers of superconductor material (30), in accordance with the method of the prevent invention.

$Bi_2Sr_2Ca_1Cu_2O_x$ (Bi 2212) high-temperature superconducting material in powder or pellet form is melted in an alumina crucible (12) using an electric furnace (14) of the apparatus (10).

High temperature superconductor (HTSC) precursor powders which are blended, calcined and annealed by external vendors are melted in an alumina crucible utilizing an electric resistance furnace. The powder is compacted and added in pelletized form. The pellets are charged directly into a preheated crucible assembly to minimize the occurrence of possible deleterious chemical reactions between the charge material and crucible or loss of alloying constituents. An inert gas such as argon protects the molten bath from reaction with oxygen which maintains melt purity. The material is melted and heated sufficiently to insure that the melt is of uniform temperature prior to fiberization.

The Bi 2212 melts completely at 1650° F. (phase change). The melt, however, is superheated to 1720° F.–1740° F. to reduce its viscosity. Once the melt is well established, it flows freely at (18) from a small hole (16) at the bottom of the alumina crucible (12). The melt forms a continuous stream which might break up into separate droplets at (20). The melt falls through a high-temperature ceramic collar (22) in the furnace, which is used to stabilize the melt stream and prevent it from wavering. The molten stream is then subjected to a high velocity fiberizing gas stream (24) inside a blowing nozzle (26) mounted in the vertical direction. The high velocity gas generates enormous shearing rates on the surface of the molten stream which transform the Bi 2212 melt into fine ligaments. The ligaments in the molten/ glassy state undergo further shearing and cooling inside a barrel (28) of the nozzle (26). The filaments become long and thin and reach complete solidification producing fibers (30). Some of the melt produces small flakes and nearly spherical shot. The blown material is collected downstream on a porous cloth (32) in a vented collecting chamber (34). The blowing nozzle (26) is a modification of the nozzle in U.S. Pat. No. 4,828,469. The modified nozzle is here designed specifically to accommodate the thermal and fluid characteristics of the Bismuth-based superconductor melts; namely, to match the viscous behavior and cooling characteristics of these melts. Furthermore, the new nozzle is designed to bring the high velocity shear layer in close proximity of the droplets so that fine fibers are stripped from the melted superconducting material. The objective of the modified nozzle is to obtain thin fibers with length-to-diameter ratios in the range of 1,000 to 10,000. The produced fiber is very flexible and ranges in diameter from 1 to 10 microns (μm) with lengths of about 25 to 50 millimeters. The nozzle is operated at supersonic speeds and with a gas supply (36) of air sufficient to produce pressures between 10 and 20 psig for best results. Of course other gases may be employed, for example, steam, argon, nitrogen or helium. FIGS. 9 and 10 show the effect various gases have on the fiberization process. FIG. 10 shows how helium gas makes better fibers with less waste than argon gas.

The present invention addresses one of the major obstacles facing the development of high-temperature superconductors; namely, the problem of brittleness. Most of the materials produced from HTSC powders exhibit poor mechanical properties and therefore cannot be used reliably in commercially-useful devices. In addition, these materials have only been produced in simple shapes, such as small pieces of wire, tape and thin film and methods of mass production are still lacking. The flexible fibers of the invention can reliably be made on a mass production basis using the gas jet blowing technique.

The major advantages of the present invention are that: the fibers formed from the HTSC material are very flexible which permits the formation of rope and other forms of fiber bundles which can be flexibly shaped into useful applications, such as for motors, generators, transformers, magnets, power lines, levitated trains and medical imaging systems.

Long slender fibers are an attractive shape for a superconducting material because they can be combined into a superconducting-normal metal composite having an enormous overlap area for current transfer between fibers. Also the 1–10 micron (μm) diameters and length-to-diameter ratios of 1,000 to 10,000 of these fibers are ideal for the development of multi-filamentary superconducting wire.

Although the present invention has been described in terms of Bismuth 2212 HTSC material, fibers can also be produced from the Bismuth 1112, lead-bearing Bismuth compounds and other non-bismuth-based materials. Newly-developed and existing superconducting material could also be suitable candidates for the production of flexible fibers as long as they possess the appropriate thermal and fluid properties for good fiberization.

Returning now to FIG. 1, the apparatus (10) includes an insulated sleeve of high temperature refractory material (38) which contains a central passage (40) in which the crucible (12) and collar (22) are positioned. This chamber is surrounded by a heating coil (42) which is connected to an electric power supply (44), for heating the crucible and collar to the melting temperature of the material in the crucible and above. An inert gas such as argon is supplied to the crucible to protect the molten bath from reaction with oxygen. This maintains the melt purity.

A temperature sensor (46) is advantageously connected to the crucible (22) for sensing the temperature of the crucible, and a pressure sensor (48) is connected to an inlet chamber (50) of the nozzle (26). A converging deflector or disc (52) is positioned within inlet chamber (50) for deflecting the air supply (36) downwardly in the direction of flow (24), for transforming the stream droplets (20) into ligaments which solidify in the barrel (28) and form fibers (30). While air is used for the fiberizing gas in this example, it is understood that other suitable fiberizing gases include and are not limited to steam, nitrogen, argon, helium, or any mixture thereof.

A collecting air or gas supply line (54) also directs air or other gas against the collecting cloth (32). This air is vented from the collecting chamber (34) through an exhaust (56).

In practicing the present invention, it was found that the temperature of the superconducting material in the crucible must be raised up to 100° above its melting point to ensure that the melt is sufficiently fluid to flow through the opening in the crucible (12). Only after the higher temperature range was reached, was a plug (not shown) in the opening (16) removed to initiate the stream (18).

It was also important to investigate droplet formation. There are several distinct mechanisms for droplet breakup depending on the value of the Weber number (We) and LaPlace number (La) which are expressed by

1) $We=(\rho_a U^2 D)/\sigma$

2) $1/La=\mu^2/\sigma\rho D$

ρ_a is the air density, U is the local air velocity, σ (sigma) is surface tension, ρ is melt density, μ is melt viscosity and D is the diameter of the undisturbed droplet. The Weber number is the ratio of the aerodynamic force to the droplet surface tension and the inverse LaPlace number is the ratio of the viscous force to the surface tension force on the droplet.

The manner in which liquid droplets disintegrate is found to depend on the range of the Weber number as shown in FIG. 3. For Weber numbers under about 10 there is no breakup; between about 10 and 25 there is a bag mode; between 25 and 50 there is an umbrella mode; between 50 and about 1000 there is a stripping of ligaments from the periphery of the deformed droplet; above 1000, atomization begins. Ligament type breakup is desirable for fiber production because it yields more fibers and less shot. FIG. 2 shows the ligament mode breakup. For this reason, the liquid does not solidify until the last stage where filaments and shot of the high temperature superconductor are formed. For 1/La less than 0.01, ligament formation and fiberization requires a Weber number in the range of 70, and the effect of the LaPlace number was found experimentally to be small as shown in FIG. 3. For inverse Laplace numbers greater than 0.01, the Weber number must be somewhat larger to achieve fiberization.

According to the invention, in addition to reducing the viscosity of the melted superconducting material, down to about 1 poise at the superheated level, it is also important to utilize a nozzle (26) of particular dimensions and design which have been found to be critical.

Referring now to FIGS. 4 and 5, nozzle (26) is structurally similar to the nozzle disclosed in U.S. Pat. No. 4,828,469, which was mentioned above, however a careful selection of the relative dimensions and positions for the elements of the nozzle are critical to forming superconducting fibers that are flexible and which also have the desired length-to-diameter ratio. The nozzle is designed specifically to accommodate the thermal and fluid characteristics of the Bismuth-based superconductor melts, namely to match the viscous behavior and cooling characteristic of these metals. The Bismuth-based and other high temperature superconductor material have a relatively narrow fiberization temperature window due to the sharp change of melt viscosity with temperature compared to glasses and alumina-silica melts. Therefore, the nozzle of the present invention is placed in the vertical direction immediately beneath the furnace to prevent the melt stream/droplets from cooling before they reach the blowing nozzle (26).

Furthermore, the nozzle of the present invention is designed to bring the high velocity shear layer of air in close proximity to the droplets so that fine fibers are stripped from the melted superconducting material as illustrated in FIG. 2.

Returning now to FIGS. 4 and 5, the various dimensions which are illustrated in the Figures have been found to have the following optimum values, for making flexible fibers of superconducting material having the desired characteristics set forth in this disclosure:

Barrel inside inlet diameter	a = 1.25"
Barrel inside outlet diameter	b = 1.60"
Barrel length	c = 13.80"
Barrel bore taper angle	d = 0.73"
Disc inside inlet diameter	e = 2.00"
Barrel outside inlet diameter	f = 1.61"
Disc inside outlet diameter	g = 1.102"
Disc axial length	h = 0.844"
Disc minimum annular outlet thickness	i = 0.040"
Axial overlap between disc and barrel	j = 0.140"
Radial annular gap between disc outlet and barrel	k = 0.034"
Air chamber inside diameter	m = 2.09"
Axial length of barrel in air chamber	n = 1.67"
Chamber axial length	o = 1.82"
Minimum annular gap between disc and barrel	q = 0.02"
Radius of barrel inlet end	R1 = 0.09"
Disc inlet passage radius	R2 = 1.50"
Disc outside radius	R3 = 0.344"

Of these measurements, the most critical is the minimum annular gap q of about 0.02" which has been found to be particularly instrumental in achieving the fibers of the desired characteristics. The other dimensions are also important.

Next, referring to FIG. 6, there is shown another embodiment of the present invention which is similar to the embodi-

ment depicted in FIG. 1 with the following modifications. An inert gas line (**82**) connected to a supply (not shown) provides an overpressure of a gas like argon to protect the molten bath of superconducting material from reaction with oxygen. A pipe (**60**) attached to a supply of gas (not shown) is connected by way of a T connector (**62**) to heater (**64**) situated at one side of the collecting chamber (**34**) and to a secondary gas supply nozzle (**66**). Nozzle (**26**) is connected to the heater outlet via line (**36'**) so that the nozzle (**26**) is supplied with the heated gas. The heater (**64**) should be capable of heating a gas in a temperature range from between 150° F. to 750° F. As mentioned earlier, suitable gases include air, steam, nitrogen, argon or helium.

Gas at ambient temperature may be optionally directed opposite nozzle (**26**) to provide a gas cushion at the bottom of collecting chamber (**34**). A fine mesh screen (**68**) is positioned across the bottom of collecting chamber (**34**) to assist in the fiber collecting process and to prevent any debris from blocking secondary nozzle (**66**).

The secondary gas supply nozzle (**66**) assists the fiber collecting process by blowing the completed fibers up and away from the products of incomplete transformation which include spherical shot particles and flakes which are collected on screen (**68**) for recycling and/or disposal. Alternately, the bottom of collecting chamber (**34**) may be hopper-shaped to facilitate collecting and recycling the products of incomplete transformation.

Similarly, a fan (**80**) may be employed to direct or pull the discharged fibers to the collecting filter (**32**). In this manner, a costly fiberizing gas such as helium may be recycled after the discharged fibers are removed by the collecting filter (**32**).

A moisture trap (**70**) and oil filter (**72**) are preferably positioned in the pipe (**60**) outside the collecting chamber (**34**) to remove contaminants from the gas supply. Gate valves (**74**) and regulators (**76**) in pipe (**60**) are employed for isolating and regulating the heated gas system from the ambient gas system. A flow meter (**78**) may be utilized for accurately measuring the gas flow.

The initial step of the fiberization process involves having a gas such as air flow going through the circulation heater (**64**) at about 100 standard cubic feet per minute (SCFM). The electric heaters are then energized and the outlet air temperature is adjusted to match the type of material that one intends to fiberize. The temperature range can fall between 150° F. to 750° F. Once the heater (**64**) has achieved steady state, the load is charged into the crucible (**12**) above the nozzle (**26**). Within a few minutes, molten droplets (**20**) exit the bottom of the crucible (**12**) through the crucible tap hole (**16**) and enter the top of the fiberization nozzle (**26**) where the droplet is passed through the high velocity heated air stream.

As evidenced by FIGS. **7** and **8**, the use of superheated injected gas provides the following advantages over ambient gas. It provides the ability to regulate the primary gas temperature in order to match up with a specific type of superconducting compound. It reduces the size of droplet feeder balls to a minimum, which in turn increases the quality and quantity of the fiber. Feeder balls are undesirable because they diminish packing density in microfilamentary composites which lower their superconducting performance. It provides the ability to produce flat, thin flake along with the fiber which can be used as a filler between the fiber matrix. It reduces the moisture content in the primary air supply which is harmful to the fiberization process.

Although the heated primary air supply was developed for raising the yield of superconducting fiberization, this heated air is applicable in the manufacturing of ceramic fiber which should also increase the yield of that material.

While a specific embodiment of the invention has been shown and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. An improved apparatus for producing inorganic fibers, comprising:

a furnace containing a heating space;

a crucible having a hole for discharging a stream of fluid material, said crucible being positioned in the heating space of the furnace;

a nozzle positioned below said crucible for receiving the stream of fluid material and for receiving a primary flow of heated gas for transferring the stream into broken up ligaments, said nozzle having a barrel through which the ligaments fall and solidify into inorganic fibers;

a heater for heating the primary flow of gas supplied directly into said nozzle; and

a collection chamber situated to receive the inorganic fibers.

2. An improved apparatus as recited in claim **1**, further comprising:

a filter in said collection chamber for gathering the inorganic fibers; and

means for directing the inorganic fibers to said filter.

3. An improved apparatus as recited in claim **1**, wherein said heater heats the gas to a temperature ranging from between 150° F. to 750° F.

4. An improved apparatus as recited in claim **3**, wherein the heated gas is a member selected from the group consisting of air, steam, nitrogen, argon, and helium.

5. An improved apparatus as recited in claim **1**, wherein the heated gas is a member selected from the group consisting of nitrogen, helium, and argon.

6. An improved apparatus as recited in claim **1**, wherein the heated gas is a member selected from the group consisting of helium and argon.

7. An improved apparatus as recited in claim **2**, further comprising means for recycling the heated gas after the inorganic fibers are gathered on said filter.

8. An improved apparatus as recited in claim **1**, further comprising means for removing contaminants from gas supplied to said heater.

* * * * *

⑲日本国特許庁（JP）　　⑪特許出願公開

⑫公開特許公報（A）　平1－224063

⑮Int. Cl.⁴　識別記号　庁内整理番号　㊸公開　平成1年(1989)9月7日

B 05 B 7/06　　6762－4F

審査請求　未請求　請求項の数　1　（全7頁）

㊿発明の名称　液体噴霧装置

㉑特　願　平1－11799

㉒出　願　平1(1989)1月20日

優先権主張　㉜1988年1月21日㉝米国(US)㉛146,631

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㉔代 理 人　弁理士 尾股　行雄

明　細　書

1．発明の名称

液体噴霧装置

2．特許請求の範囲

1．収斂したガス入口部を有するノズルと、閉塞部と、拡開状の噴霧出口部とを備え、上記閉塞部は上記ガス入口部と上記噴霧出口部との間に介装して両者を結合している超音速にて液体を噴霧する装置において、上記噴霧出口部は、選択された距離の下流部の面積Aとノズルの喉部の面積A＊との関係が下の式を満足し、

$$\frac{A}{A^*} = \frac{1}{M}\left[\frac{2}{\gamma+1} + \frac{\gamma-1}{\gamma+1} M^2\right]^{\gamma+1(2(\gamma+1))}$$

（但し、M＝音速に対するガス流の速度の割合であり、γは2相ガス混合物の比熱の割合）

更に、液体入口を備え、この液体入口が上記閉塞部内にて終端して液体を上記閉塞部に導き、上記ガス入口からのガスを混合して2相混合物を構成するようにした、液体噴霧装置。

3．発明の詳細な説明

＜産業上の利用分野＞

この発明は液状物質を噴霧する装置に関し、更に詳しくは、所定の断面積において液滴の均一な分布となるように液体を噴霧する装置に関するものである。

＜従来の技術と問題点＞

従来、液体を液滴にして滴下する手段として多くのものがあるが、最も一般的なものとしては、液流を剪断（切断）することがなされている。この剪断には幾つかの方法があり、霧化された液滴の粒度分布が採用する方法の幾つかの要因に基づいて制御される。剪断の最も簡単な方法は所望の形状の絞り部から液を強力に噴射させて液流の振動を増加させることである。液流の中に切断装置を挿入して二次的な剪断を得るようにも出来る。また、大気抵抗剪断と称さ

れる如く、液体を自由に落下させるなどの方法により、液流が通過する大気の抵抗によって別の剪断を得ることが出来る。剪断については、振動装置によっても得ることができる。フィラメントが紡糸ディスクを離れるときに液体フィルムをを剪断する事も出来る。更に、液流と、ガスまたは液体の第2の流路とを交差させることによっても得ることが出来る。最も一般的な二つの方法は、最初と最後の方法の振動によるものである。

これらの技術の応用範囲は水の噴霧から、塗料、殺虫剤、医薬品の噴霧、そして特別な金属学的応用のための金属粉体の形成に至るまで種々の分野に応用されている。しかし、多くの場合、エネルギーの要求の度合いが高いことと複雑さによって、単純さと簡単さに長じた本発明よりも優れたものとはなり得ず、かつ本発明に無い特長を備えたものではない。しかしながら、固有の大きさの範囲で要求される均一な液滴の粒度分布が必要とされる多くの方法、工程において改良の余地がありその可能性がある。予期される通り、サイズが小さくなればなるほど、上記の改良を達成することは困難となる。苛酷な環境や有害物質を使用するケースにおいて液滴の形成が要求されるときは、多くの工程を改良することが出来る。スプレー装置の形状や構造を改良変形させ、ガスのエネルギーを増大させることによって、異なる2種類の流体システムでの液体と気体との結合を改良するための多くの試みが成されてきている。加えて、気体の流れに音波または超音波の振動を与えて粒度分布を制御することも出来よう。このような試みは米国特許第 2,997,245号、同第 3,067,956号、同第 3,829,301号及び同第 3,909,921号に開示されている。一般に、気体の速度若しくは振動周波数に直接関与し得る粒度分布については未だ公表されていないが、その理由は、従来技術のこれらの構成での粒度分布が全体的な気体の流れだけに直接関与するものであったからである。気流と液流が結合する場合、2相の流れの音速は考慮されなかったのである。従来の技術では非常に粒度の小さいものは可能であったが、得られた粒度は第2の流れの周波数に関与すると言うよりも、増大したガス圧により多く関与していたものである。

<問題点を解決するための手段>

この発明は、粒度分布が所定の狭い範囲内にて制御できるように超音速の2相の噴流で剪断することによって液体を噴霧する噴霧装置であり、その結果、断面が比較的均一であり、噴霧断面の膨脹が最少となるようにしたものである。この装置は制御可能とするものであり、気体質量に対する液体の割合と2相混合体が調整されて、所定の音速を得、これにより、音の衝撃波と与えられた音波の周波数とがノズル内に保持されることになる。このような調整によって、気体のエネルギー間の結合が衝撃波、音波周波数及び音速という形で生じ、さらに、液体が剪断されて最適エネルギーが液体に伝達され、引き続き液滴が形成される。付与された周波数は粒度に応じて選択でき、好適な粒度よりも大きめの液滴を砕解し、そしてこれらを更に小さく凝集し、これにより実質的に均一な粒度の噴霧が達成されるものである。

本発明は、収斂したガス入口部を有するノズルと、閉塞部と、拡開状の噴霧出口部とを備え、上記閉塞部は上記ガス入口部と上記噴霧出口部との間に介装して両者を結合している超音速にて液体を噴霧する装置において、上記噴霧出口部は、選択された距離の下流部の面積Aとノズルの喉部の面積A＊との関係が下の式を満足し、

$$\frac{A}{A^*} = \frac{1}{M}\left[\frac{2}{\gamma+1}+\frac{\gamma-1}{\gamma+1}\quad M^2\right]\gamma+1(2(\gamma+1))$$

（但し、M＝音速に対するガス流の速度の割合、であり、γは2相ガス混合物の比熱の割合）

更に、液体入口を備え、この液体入口が上記閉塞部内にて終端して液体を上記閉塞部に導き、上記ガス入口からのガスを混合して2相混合物を構成するようにした、液体の噴霧装置である。

＜実施例＞

以下、この発明による好適な実施例について図面を参照して説明する。

第１図と第２図は、この発明の音速噴霧装置のそれぞれ異なる実施例を示している。異なる実施例ではあるが、液体の供給入口３（第１図）および３ａの設置位置を除けば両者は同じと考えてよい。第２図の実施例の場合をインライン（直線）型とし、第１図の構成を直交型の噴霧装置とする。図示されたのは、ノズルの断面図であり、これは円筒状であってもよいし、矩形状であってもよい。また、図面の紙面に対して直交する部分の大きさについては格別の制限は無い。

第１図において、ノズルのガス入口部101は閉塞状のチョーク部102にて最小に収斂し、次いで、出口部103にて末広状に拡開した構成となっている。この発明で用いられる好適な気体は噴霧装置の材質に適合すると共に、噴霧される物質とも適合する類いの気体である。かかる気体としては、アルゴンガス、窒素ガス、ヘリウムガス、ネオンガス、などの不活性ガスがある。利用分野によっては空気などのガスも使用出来る。

第１図において、噴霧ガスはガス送り部１から送り込まれる。このガス送り部１はエレメント２によって温度制御することができる。ガス送り部１は収斂部で終端し、その位置が収斂・拡開ノズルのチョーク部 102となる。液体送り部３も温度制御が可能でありノズル100 のチョーク部102 の近傍にて直交して設けてある。換言すれば、液体送り部３はガス送り部101 からのガスの流れに対して直交して入り込むように位置しているのである。液体送り部３の正確な位置は、採用する組成物の割合あるいは種に主として依存し、更に、２相の混合物の音速にも依存するであろうから、液体の送り部３の位置は上記チョーク部102 に関して調整することが出来よう。この相対位置によって、噴霧の形状と寸法、液体の投入、噴霧の位置、等の噴霧の種々パラメータに影響を及ぼすことになる。第１図の液体送り部３は一側からのみ入り込むように図示されているが、両側に設けて一側から或いは両側から同時に供給するようにもできる。液体送り部３は１個または複数個の点状入口としても良いし、連続するスリットとすることも可能である。ノズル103 の拡開部は、２相の混合物の音速、出口の流れの特性、液滴の粒度分布によって、その長さ、形状および拡開の度合いを備える。以下に詳述する。

本装置で噴霧される液体は装置の材質に適合する物質である。非常に高粘度の液体でも噴霧し得るものである。錫、アルミニュウム、銅、鋼等の溶融金属も噴霧可能である。

第２図はこの発明の別の実施例を示し、インライン型の液体送り部３ａを採用したものである。ガス送り部１ａは第１図の場合同様にエレメント２ａによって温度制御される。インライン送り部３ａはノズル100aの収斂部101aまで延びており、２相の混合物はチョーク部にて混合され、拡開部103aを介してノズルを出る。第１図の場合同様、液体送り部は１個または複数の点状入口としても良いし、連続スリットとすることも出来る。温度はエレメント４ａで制御できる。

一般に、アトマイザーなどの噴霧装置は、その装置で形成される条件のもとで気体と液体とが相互に作用し合うと剪断による液滴の流れを形成する。この発明の装置は、気体と液体との極めて効率的な結合をもたらし、且つ、この結合がチョーク部において制御可能な条件のもとで行われるために、工程において最大限制御を可能とするものである。狭くなったチョーク部の範囲の効果については実験結果として第３図～第５図に示す。この発明装置のノズルは液体を採用した従来の装置に比較されるが、しかし、その従来の装置では収斂・拡開ノズルを有するものではない。

この発明の装置において、液体と気体とがノズルに送り込まれて、ガスチョーク部にて２相

（気体と液体）が混合し、拡開部に入り込み、そこで上記2相の混合物が膨脹して部分的に膨脹エネルギーを使用して2相の混合物を超音速にて送り出すのである。

第3図は、液体送り部に液体が無い状態でガス送り部からガスが送り込まれる際、チョーク部にて形成される定常水頭を示している。この発明のノズルは、標準リットル／分（SLPM）で測定される狭いガス流範囲でのみ吸引が形成されるのであり、この場合の最大吸引は厳密に押さえられるものであり、これに対して従来の装置では流量により増加する傾向にあるものである。

第4図は、同じ気体流の条件にて液体送り部に水を送り込んだ場合の吸引される水の量を示している（標準リットル／分、即ちＳＬＰＭで測定したもの）。吸引される水量は本発明のノズルの作動領域に亘って直線的に減少している。この点、従来の装置では、吸引される水が最大限増加し、それが蒸気圧と水温に依存し、その点にて水が蒸発し真空度を減少する。

第5図は本発明装置と従来装置の液体に対する気体の質量比を示している。この割合は従来装置の大きな範囲のガス流量については基本的に同じであるが、この発明の装置では好適に変化する。ガス流量は標準リットル／分（SLPM）にて測定される。

第3図～第5図には更にこの発明の装置の制御方法も示している。まず、図示の通り、与えられたノズルの寸法にて、吸引は非常に狭い範囲のガス流速内においてのみ発生する。しかしながら、この様なパラメータは、液体送り部の寸法を変えることにより、或いは、液体の供給圧力を変える事により変えることが可能である。上記の一方又は双方を増加させることにより、液体に対するガスの割合を減少させることができ、これにより平均液滴のサイズを増大させ、冷却を減少させるであろうが、しかし、液体の送出割合を増加させるであろう。ノズル出口の周囲圧力を増加させると、ガス圧の増加が必要となって、ガス／液体率の増加と、冷却の増加を伴う液滴サイズの減少を確実にするが、液体の流量増加は無いのである。

上記のパラメータは、ノズル出口での圧力が周囲圧力に匹敵するような条件である。構造的な寸法は一次元的な安定流量の計算から、先ず、下記式のＡ／Ａ＊を決定することで達成される。

$$\frac{A}{A^*}=\frac{1}{M}\left[\frac{2}{\gamma+1}+\frac{\gamma-1}{\gamma+1}M^2\right]^{\gamma+1(2(\gamma+1))}$$

（ここで、Ｍはマッハ数値即ち、音速に対するガスの流速の割合であり、Ａはノズルの喉部の或る下流位置の面積、Ａ＊はノズルの喉部の面積、γは２相の混合物の比熱の割合を示している。）

与えられた下流位置でのＡ／Ａ＊値は、使用における２相の混合物と速度に依存して変化する。次に、ホドグラフ構成法のごときノズル形成の分野で周知の方法にてノズルの長さと形状を決定する。この方法は、図形と計算による手法で、与えられたノズルを通る超音速の流れによってもたらされる衝撃を最小にするものである。しかしながら、従来のノズルを、上記の式とＡ／Ａ＊値に基づいて変形改良することが出来る。いづれの方法も２相混合物のγ値の推定値または経験的な決定を必要をするものである。

この発明の超音波ノズルの重要な点は、スプレーの出口形状を調整できるという事である。出口圧が周囲圧に等しくなると、スプレーはノズル出口と同じ断面を保持する。出口圧が低い場合は、スプレーは収斂するし、逆に高い場合は、拡散する。従って、噴霧されるスプレー出口形状を予め決めることができる。

この発明において、衝撃もしくは噴霧条件と同じように超音速条件は、剪断により液体を粉砕して吹き付けガスによって微細な液滴を形成し、２相フローを形成する。本発明の装置で採用する方法としては、液体送り部の位置は変更出来るものであり、変更によって液体の吸引を制御して液の流量を制御出来るし、吹き付けガ

スによる剪断の制御も可能となる。出口水柱の形状を決めることができること、およびその水柱での液滴の分布に影響を与えることができることは、この発明装置の持つ優れた効果でもある。

好適な実施例としては、収斂・拡開構造の超音速噴霧ノズルであり、その出口は円形または直線状であり、ノズル内にて2相混合物用として好適な超音速条件が達成されるようになっている。液滴の質量と粒度はこの速度、衝撃条件、衝撃と2相の結合に影響を及ぼす。逆に、衝撃条件と上記両者の結合は、ノズル内での液滴粒度と液滴分布に影響を与える。混合物はチョーク部で詰まることになり、かくして、ガスの閉塞速度よりも充分低い速度にて振動することになり、これによって、従来のノズル構成の場合よりも低いガス送り圧にて液体の結合と砕解を可能にしている。

衝撃周波数は増加することができ、例えば、狭い液滴粒度分布を選択する場合には超音波周波数を適用できる。液滴粒度分布は、大きな液滴を砕解してより細かくした分布液滴を凝集することにより細密にすることが出来る。ノズルの形状、長さ及び圧力により、また、機械加工のマークなどのノズル表面に周期的な凹凸を付し、或いは、チョーク部の前にてガスに周波数をかけることにより、周期的な衝撃を達成できる。

液体送り部3及び3aの端部の位置によって、噴霧特性が影響される。チョーク部102,102aの後部または前部に設置することにより、吸入若しくは液体送り部の背圧の量を増加または減少させ、かくて、液圧との組み合わせを考慮して液体の流量を決定するのである。このようにして、液圧、ノズル出口圧、ガスフローおよび圧力を変化させることにより、流量を制御できるのである。これにより、工程中に条件や要求事項を変化させて、噴霧パターン、水柱密度と液滴の粒度分布の制御が可能となり、更に、チョク部に対する液体入り口の位置を調整することと併用させて、噴霧を更に制御することが出来る。

噴霧制御の別の態様としては、液体と気体のいづれか一方、又は双方の温度を制御することである。必要な全ての条件が満たされた後、液体送り部の液の凍結、或いはノズル内の凍結を防止するためには、この温度制御は必要であろう。温度制御の別の意義として、音速条件が温度依存的であり、位相間の熱平衡度に依存していることが挙げられる。更に別の必要性としては、出口での液滴温度を変化させること、位相の相互作用からの加熱または冷却の補償、並びに、2相混合物の膨脹から冷却のための補償を行うこと、がある。

<u>具　体　例</u>

液体錫の噴霧用として一点直交型液体送り部を有する筒状ノズルを形成した。ノズルは38°のコーン（円錐形）入り口と17°のコーン出口を有する。出口コーンは、絞り部（チョーク部）の10倍の径を有する出口にて終端している。チョーク部にて16標準リットル／分（SLPM）のアルゴンガス流が達成され、液が送り込まれない状態の液体送り部での定常水頭（static head）が3.9psiとなった。次いで、ノズルの液体送り部を通して蒸溜水が吸入され、同時にノズル出口圧を周囲圧に等しく維持された。この結果、6グラム／分の水流が得られ、水に対するアルゴンガスの質量率が4.0であった。その結果得られる噴霧は、均一な断面と均一な粒度分布が観察された。

この発明において、噴霧装置の材質に化学的に適合するものであれば、どのような液体でも噴霧することが出来る。非常に粘性の高い液体でも噴霧可能である。明らかに2相の混合物の音速振動はかかる高い可能性に深く関係し、液体を剪断して噴霧を形成する粒度にする。かくして、鋼、錫などの溶融金属を含むどのような液体でも実際に噴霧可能である。同様に、噴霧装置の材質及び噴霧される液体に適合するものであればどのようなガスでも噴霧できるわけで

ある。

更に、異なる２個の液体送り部から異なる液体を送り込むことも可能である。この様な場合、相対的な送り度合いの調整をして、対応する液体の粘性、蒸気圧、表面張力などの相違を補償することが要求されよう。更に、この様な構成は同質性の噴霧となる一方、個々の液体の個々の粒度形成が噴霧内において変化する。それぞれの送り部の位置が相違すれば噴霧の粒度と形状に影響する。

以上この発明の好適な実施例について説明したが、この発明はこれらの実施に限定して解釈されるものではなく、特許請求の範囲の欄に記載の範囲内で種々変更可能である。

４．図面の簡単な説明

第１図はチョーク部近傍に液体送り部を設けたこの発明の第１の実施例による噴霧装置のノズルの説明図。第２図は液体送り部をインライン構成に配設したこの発明の第２の実施例を示す説明図。第３図は第１図と第２図の液体送り部に液が無い状態でガス流により形成される定常水頭を示したもので、本発明装置と従来装置とを比較したグラフである。第４図は第１図と第２図の装置のガス流に関連して吸入される水の量について、従来装置と比較したグラフである。第５図は第１図と第２図に示した装置のノズルについて吸入される液体に対するガスの質量比を示すものであり、従来装置と比較したグラフである。

１…ガス送り部、２，４…温度制御エレメント、３…液体送り部、101…入口部、102…チョーク部、103…出口部

特許出願人　アメリカ合衆国

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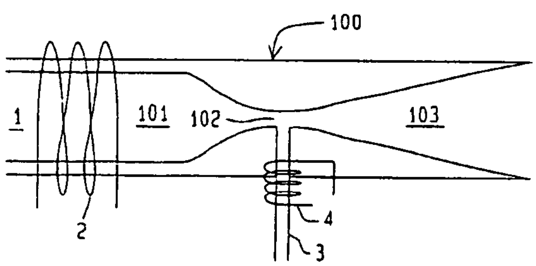

FIG. 1

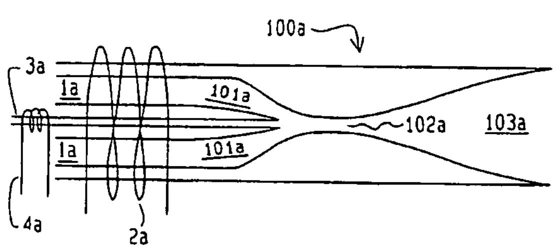

FIG. 2

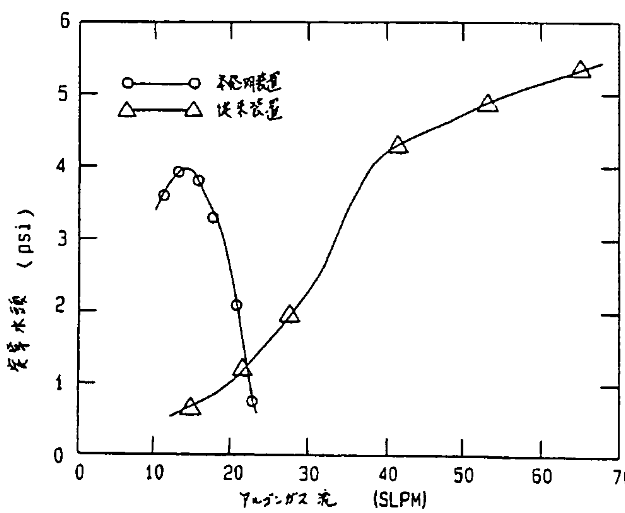

FIG. 3

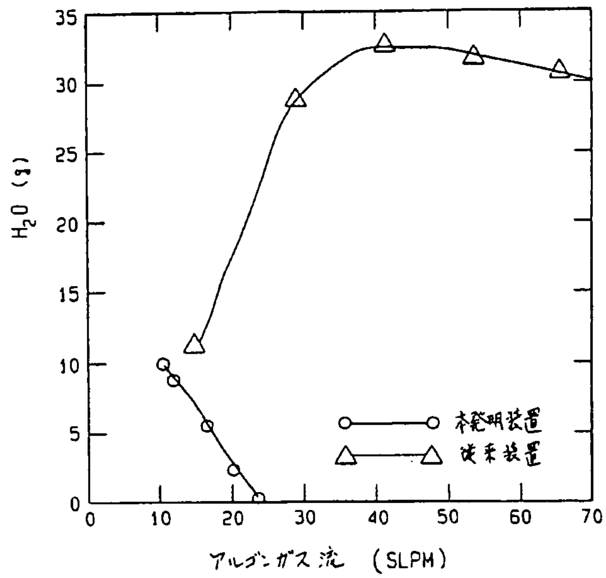

FIG. 4

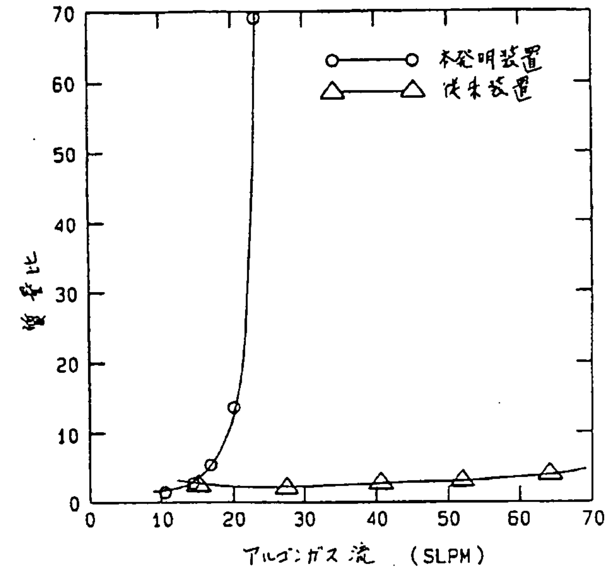

FIG. 5

PAT-NO: JP401224063A

DOCUMENT-IDENTIFIER: JP 01224063 A

TITLE: LIQUID SPRAYING DEVICE

PUBN-DATE: September 7, 1989

INVENTOR-INFORMATION:

NAME	COUNTRY
ALVAREZ, JOSEPH L	N/A
WATSON, LLOYD D	N/A

ASSIGNEE-INFORMATION:

NAME	COUNTRY
USA GOVERNMENT	N/A

APPL-NO: JP01011799

APPL-DATE: January 20, 1989

INT-CL (IPC): B05B007/06

US-CL-CURRENT: 239/79, 239/135 , 239/434 , 239/434.5

ABSTRACT:

PURPOSE: To simply and easily form liquid drops of a uniform distribution by forming the spray outlet part of a device for shearing and spraying liquid by generating supersonic jets of two phases from a closing part to the diverging spray outlet part to a specific sectional area.

CONSTITUTION: Spraying gas is subjected to temp. control by an element 2 and is fed from a gas feed section 1. This gas feed section 1 terminates at a converging part and the position thereof constitutes a choke part 102 of the

converging and diverging nozzle. A liquid feed section 3 is also controllable in temp. and is disposed orthogonally near the choke part 102 of the nozzle 100. Various parameters, such as the shape and size of the spray, the feeding of the liquid and the position of the spray, are affected by the relative positions thereof. The diverging part 103 of the nozzle is so formed as to satisfy equation I((where, M = the ratio of the velocity of the gaseous flow to the velocity of sound, r = the ratio of the specific heat of a two-phase gaseous mixture) between the area A in the downstream part of a selected distance and the area A* of the throat part of the nozzle.